Extending the Applicability of Iso-inertial Eccentric Training

A thesis submitted to the College of Graduate and Postdoctoral Studies
In Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy
in the College of Kinesiology at the
University of Saskatchewan

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Abstract

Background: Eccentric (ECC) training has been widely studied because it has the potential to produce high forces, which can enhance gains in strength and muscle hypertrophy. In light of this potential, a disconnect exists between laboratory studies on ECC training and what is commonly performed by exercisers. **Purpose:** The goal of this thesis was to extend the applicability and accessibility of ECC focused training by furthering the knowledge of ECC training performed with common equipment using practical, easy to perform protocols. **Study One:** Study one compared supramaximal to submaximal ECC training. Results indicated that when training to volitional fatigue, there was no difference in muscle hypertrophy between submaximal and supramaximal ECC training, and submaximal ECC training sessions were perceived to be easier. These results advance the understanding of high vs. low intensity training for muscle hypertrophy and suggest that submaximal ECC training may be an effective alternative strategy to supramaximal ECC training. **Study Two:** Study two investigated approaches to manipulate the level of involvement of the ECC phase of contractions in conventional lifts. Findings indicated that when comparing CON only to conventional training, or CON with an emphasized (longer) ECC phase, all increased CON strength compared to control, but only the CON with an emphasized ECC increased muscle hypertrophy compared to control. This study provides evidence that emphasizing the ECC phase of a lift is an effective way to enhance muscle hypertrophy without sacrificing CON strength increases. **Study Three:** The purpose was to explore the interplay of contraction type and intensity on iso-inertial and isokinetic strength and muscle hypertrophy. The main finding of this study was that across both training contraction types, high intensity training was superior to low intensity for increasing both iso-inertial and isokinetic strength. Additionally, ECC was more effective for muscle hypertrophy than CON, regardless of training intensity. Together, these findings highlight the specific response of training intensity and contraction type and add knowledge regarding the transferability of strength across modalities. **Conclusion:** The findings of this thesis verify the effectiveness of iso-inertial ECC training, advancing both the theoretical understanding, and the practical implementation of these protocols.

Acknowledgements

"For your thoughtfulness and generosity, from you I have learned much of life's philosophy. Thank you sincerely."

- author unknown

Wow, what a ride. Completing this Ph.D. has been one of the most challenging things I have ever undertaken but in the end I would not change a thing…well maybe a couple things, including trying to finish a bit quicker, but you get the point. The following is a list of sincere thanks to the many, many people who have helped me get to this point. The quote above basically summarizes how I feel collectively about you all….**Thank you sincerely!**

First and foremost, to my supervisors, Jon and Phil. Thank you is not enough but that is where I will start. Coming back to the U of S to work with you both for my Ph.D. is one of the greatest decisions I have ever made and I don't know where my career path would have unfolded had I not made that move. You have always treated me as a colleague, allowing me to develop my own ideas, and carve my own research identity, all while providing much needed support, guidance, mentorship and gracious generosity of your time and expertise. I have always looked up to you both and consider you role models on how to be both a great academic and an incredible family oriented father and husband. I look forward to many more years of friendship and collaboration.

To the members of my committee, thank you Joel, Alison and Sandra. Your expertise, support, patience, guidance, and ongoing encouragement throughout this entire process have been awesome. From input into my projects, revisions to my documents, your emails with words of encouragement and everything else, your contribution to my completion of this process is more significant than you know.

To my external examiner, Dr. Ken (Kazunori) Nosaka, thank you for agreeing to serve as the external examiner for my thesis defence. It was an honor to have you read and evaluate my work. Your enthusiasm to be involved, even though it meant joining us via Skype for a 6am defence start time in Australia, is greatly appreciated.

To my friends, teammates, lab members, and fellow grad students, thank you for your advice, for always being there to bounce an idea off of, but most importantly for your friendship. You made coming to the lab, or the PAC, or wherever work was that particular day enjoyable. More so, the fun spent outside of work has led to lasting memories that will carry on just as long as any data collected or abstract written. Friends and teammates away from school, thank you for keeping me sane during this process and for your continued support, even if you didn't always know what I was doing or why it was taking so long. In roles both large and small, your friendship and belief in me have been awesome.

Huge thank you to all of the organizations that have contributed financially to the completion of my Ph.D. Specifically, I would like to acknowledge NSERC (Natural Science and Engineering Research Council) for graduate funding in both my Master's and Ph.D. Without NSERC funding my transition on short notice back to work at the U of S would have been much more difficult and thus the academic freedom that this funding allowed has been crucial to my success. Also, to the College of Kinesiology and the University of Saskatchewan for continued funding through my Ph.D. and for being a fantastic place to work, study and train for a career in academia, my sincere gratitude.

To my current colleagues at Brandon University, thank you for your encouragement since I have started working at BU. You never doubted my ability to wrap up and finish this Ph.D. and your encouragement and interest in my work has provided day to day inspiration needed to get to the finish line. I look forward to our years ahead working together.

Dedication

"Families are the compass that guide us. They are the inspiration to reach great heights, and our comfort when we occasionally falter."

- Brad Henry

This thesis is dedicated to my family. Mom, Dad, Kalee, Dylan and Khloe. Throughout this entire process (and really throughout my entire life) you have been a constant source of unconditional love, support, and happiness. Tackling anything in life is made easy when I know that no matter the outcome I always have you all by my side. I hope you know that all my achievements are also your achievements and that any success I have is shared with you. Thank you for everything that you do and for always being there for me. I love you all and truly cherish all of our time spent together.

Also, along with my immediate family this thesis is also dedicated to members of my extended family, especially my grandparents Sylvester and Marion Krentz and the late Alex and Viola Bender. Your love, hard work and dedication to your family paved the way for all of the opportunities available to your children, grandchildren, and great grandchildren. By putting your family first, you have allowed all of us to strive towards our goals and dreams.

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List of Abbreviations

ACSM: American College of Sports Medicine

ANOVA: Analysis of variance

ANCOVA: Analysis of covariance

CON: Concentric

COPD: Chronic Obstructive Pulmonary Disease

ECC: Eccentric

F: Female

GG: Greenhouse-Geisser

ISO: Isometric

kg: Kilogram

M: Male

MANOVA: Multiple Analysis of Variance

MANCOVA: Multiple Analysis of Covariance

MAV: Mean Absolute Value

1RM: One Repetition Maximum

RPE: Ratings of Perceived Exertion

SD: Standard Deviation

SEM: Standard Error of the Mean

VAS: Visual Analog Scale

List of Appendices

Chapter 1 – Thesis Introduction

1.1 Introduction and Thesis Structure

Performance of resistance training leads to both health and performance related benefits (Stone et al. 1983; Martel et al. 1999; Abe et al. 2000; Burke et al. 2001; Tanimoto et al. 2006; Krentz et al. 2008; Cornish et al. 2009; Ratamess et al. 2009; Mitchell et al. 2012; Alegre et al. 2015, Stamatakis et al. 2017). Several studies have shown eccentric (ECC) training to be better for increasing muscle hypertrophy than concentric (CON) training (Higbie et al. 1996; Seger et al. 1998; Hortobágyi et al. 1996; Farthing and Chilibeck, 2003b; Roig et al. 2009). Most resistance training protocols consist of both CON and ECC phases, although conventional dual contraction training (coupled ECC and CON) often under loads the ECC phase of training because ECC contractions produce greater force than CON (Farthing and Chilibeck, 2003). ECC contractions have the potential to efficiently produce gains in strength and hypertrophy with less cardiopulmonary system stress; ideal for populations with low exercise tolerance (Roig et al. 2008). As such, incorporating ECC training has been of interest for clinical populations (e.g. chronic obstructive pulmonary disease (COPD), Parkinson's disease, and type 2 diabetes) (Rooyackers et al. 2003; Dibble et al. 2006; Marcus et al. 2008, 2013)

Considering all of the potential upsides surrounding ECC training, many gaps still exist both in the study of and incorporation of ECC training protocols. A majority of the studies investigating ECC training have utilized non-conventional devices such as isokinetic dynamometers (Higbie et al. 1996; Hortobágyi et al. 1996; Farthing and Chilibeck, 2003; Shepstone et al. 2005; Krentz and Farthing 2010). As well, many studies have utilized supramaximal ECC loading, leading to protocols associated with significantly decreased strength and delayed onset muscle soreness (Nosaka and Clarkson, 1996; Tokmakidis et al. 2003; Krentz and Farthing, 2010). Other methods of ECC training that may be more practical and applicable (i.e. protocols utilizing standard weight training equipment) or that may lead to less deleterious effects (submaximal ECC loading) have received minimal research attention.

The purpose of this thesis was to extend the applicability, practicality, and accessibility of ECC focused training by furthering the known information regarding ECC training performed with common equipment and in practical, easier to perform training settings. The current thesis utilized protocols that were safe and applicable, and incorporated readily available, common, iso-inertial equipment (dumbbells). In doing so, findings from this thesis have advanced the theoretical understanding of ECC training for muscle hypertrophy as well as the interplay of contraction intensity, and contraction type, for increasing muscular strength. In addition, practical findings of this thesis will help advance the incorporation of ECC training into everyday conventional protocols.

This thesis is structured in manuscript format with a preceding literature review (Chapter Two) and a concluding section (Chapter Six) discussing the broader, combined implications of the individual findings of three studies. Chapters Three, Four, and Five are written as unique, contained manuscripts, each with their own introduction and discussion section, which together encompass the unique scientific contributions of this thesis.

Chapter 2 - Literature Review

2.1 Synopsis

This chapter will begin with a short overview of resistance training including its benefits and specific variables that may be manipulated in designing resistance training programs. Eventually this chapter provides a more detailed description of the adaptations and commonly cited benefits and challenges associated with eccentric (ECC) based resistance training highlighting various modes used to perform ECC training. Finally, the review will identify key knowledge gaps with specific details pertaining to: the role and practicality of supramaximal versus submaximal eccentric contractions, the inclusion of ECC training in conventional concentric (CON) focused resistance training, and the interplay of training intensity and contraction types across testing and training modalities. Each section concludes with an explanation about its relevance to this thesis. The final sections will describe how the objectives of this thesis specifically fill research gaps. The broad goal of the entire thesis is to extend the accessibility and applicability of ECC training.

2.2 Resistance Training Benefits

It is unequivocal that the performance of resistance training leads to a long and diverse list of health and performance related benefits. Resistance training is known to increase strength and muscle hypertrophy (Cureton et al. 1988; Hisaeda et al. 1996; Chestnut et al. 1999; Abe et al. 2000; Burke et al. 2001; Tanimoto et al. 2006; Krentz et al. 2008; Cornish et al. 2009; Ratamess et al. 2009; Mitchell et al. 2012; Alegre et al. 2015), positively influence body composition by increasing muscle mass (Pollock & Vincent 1996; Hunter et al. 2004) and leads to an overall increased quality of life in people who have compromised fitness levels (DeBusk et al. 1978). As well, a recent pooled analysis of over 80,000 individuals highlights the important role that resistance training plays in decreasing the incidence of cancer and all-causes of mortality (Stamatakis et al. 2017). Strength training is associated with reduced risk of type 2 diabetes in men (Grontved et al. 2012) and women (Grontved et al. 2014). With regards to cardiovascular health, resistance training results in lower resting blood pressure (Stone et al. 1983; Martel et al. 1999) and a lower heart rate and blood pressure response to a given musculoskeletal load (Pluim et al. 2000; Volaklis & Tokmakidis, 2005). Overall, the mounting evidence clearly indicates that the inclusion of resistance training in one's daily life is associated with health benefits. Accordingly, both the Canadian Society for Exercise Physiology (Canadian Physical Activity Guidelines, http://www.csep.ca/CMFiles/Guidelines/CSEP_PAGuidelines_adults_en.pdf) and the American College of Sports Medicine (ACSM) (Haskell et al. 2007) recommend regular resistance training in their physical activity guidelines. Acknowledging the importance of resistance training for health enhancement, it is important to be cognizant about specific variables when implementing resistance training protocols. Strength training protocols in this thesis have been designed to specifically enhance muscle hypertrophy and muscular strength and investigate how manipulation of specific training variables alters these outcomes.

2.3 Resistance Training Variables

The American College of Sports Medicine advises that in order to stimulate adaptation towards specific goals, progressive resistance training protocols are necessary (ACSM Position Stand on Resistance Training, Ratamess et al. 2009). Two common and popular training goals are muscle hypertrophy and increased strength. Manipulation of variables such as training intensity, volume, frequency, rest between sets, and contraction type can all be strategically controlled to elicit strength and hypertrophy responses. Traditionally, high training loads (80-100% 1RM) are preferred for increasing strength and moderate to high loads (70-100% 1RM) are recommended for muscle hypertrophy (Ratamess et al. 2009) although recent investigations (Mitchell et al. 2012; Alegre et al. 2015; Krentz et al. 2017 - study 1 of the thesis) indicate that training-induced muscle hypertrophy may be similar with high and low intensity training. Training volume (encompassing the total number of sets and repetitions performed) is another important consideration when performing resistance training. Ratamess et al. (2009) recommend 1-3 sets be performed for novice resistance trainers looking to increase strength and multiple sets (3-6 specifically for hypertrophy) for advanced lifters looking to increase strength and hypertrophy. Specifically, meta-analyses by Rhea et al. (2002; 2003) indicate that 3-4 sets are the most advantageous for strength enhancement. Similarly, a recent review highlights the idea that muscle hypertrophy is most easily enhanced with the inclusion of greater training volume (Figueiredo et al. 2018).

Schoenfeld et al. (2016) investigated optimal frequencies of training for muscle strength and hypertrophy in a systematic review and meta-analysis. They indicate that for muscle growth, training twice a week is superior to once a week and recommend all major muscle groups be trained at least twice per week. Finally, rest intervals between sets influences resistance training outcomes. For exercises that are specifically designed to increase strength and which incorporate multiple joints, ACSM recommends resting 2-3 minutes between sets while shorter rest periods (1-2 minutes) are recommended for smaller assistance-based (i.e. single joint muscles which assist in more prominent multi-joint lifts) muscle groups (Kraemer, 1997; Richmond and Godard, 2004; Ratamess et al. 2009). This recommendation is similar for muscle growth in which novice and intermediate programs are to include rests of 1-2 minutes in length (Ratamess et al. 2009).

This thesis investigates adaptions that arise from resistance training protocols that are focused on the variable of contraction type. Specifically, the thesis was designed to investigate the effects of ECC training and alterations across various training intensities and protocols. With regards to other variables that have been reviewed, all resistance training programs in this thesis have been designed in accordance with current recommendations to enhance both muscle hypertrophy and strength. Specifically, all training groups were prescribed 3-6 sets per training session, trained 2-3 times per week and had two minutes rest between sets. Two of the three studies specifically investigated high versus low intensity training adaptations, while the other study utilized an intensity of 80% of 1RM in accordance with recommendations to maximize both strength and hypertrophy.

2.4 Contraction Types in Resistance Training

One critically important variable, which has not been discussed in the context of strategic resistance training variable manipulation, is the influence of contraction type. Skeletal muscle movement involves three distinct types of contractions. CON contractions occur when muscle is able to overcome a resistance resulting in the shortening of the sarcomere during contraction. Isometric contractions occur when muscle length or joint angle is kept constant as the force produced equals the external resistance. An ECC contraction occurs when muscle is lengthened while contracting due to the external load being greater than the force the muscle is producing. Force velocity curves indicate that ECC contractions are able to produce the greatest amount of force and that isometric contractions produce more force than CON contractions, which usually produce the least amount of force (Sale et al. 1987; Hortobáygi and Katch, 1990; Westing et al. 1990; Westing et al. 1991; Farthing and Chilibeck, 2003).

In their resistance training guidelines, Ratamess et al. (2009) broadly recommend the inclusion of CON, ECC, and isometric (ISO) muscle actions for novice, intermediate, and advanced lifters. Traditional resistance training usually involves at least two of the three forms of contractions, namely a CON portion coupled with an ECC portion (i.e. lifting a weight up and then lowering back down to the starting point). As ECC strength is substantially greater than CON, this form of training results in the emphasis of the lift being placed on the CON portion. As a result, the intensity prescription for conventional “iso-inertial” resistance training (often referred to as constant load resistance training) is almost always limited by CON strength. Conversely, when the ECC portion of the lift is isolated, training can be performed at intensities greater than 100% of one’s CON 1RM (referred to in this document as “supramaximal” ECC training). This thesis explores novel ways in which ECC training may be implemented during conventional (iso-inertial) resistance training. As outlined in sections below, investigations regarding iso-inertial ECC training are important to increase accessibility of ECC based training for a broader range of the population, being that iso-inertial resistance (i.e. dumbbells) is commonly available.

2.5 Eccentric versus Concentric Training for Hypertrophy and Strength

Studies investigating isolated ECC compared to isolated CON training have repeatedly touted the superior ability of maximal ECC training to induce greater muscle hypertrophy (Higbie et al. 1996; Seger et al. 1998; Hortobágyi et al. 1996; Farthing and Chilibeck, 2003b; Roig et al. 2009). Other studies comparing ECC to CON controlling for work (Moore et al.

2005) or volume (Hortobágyi et al. 1996) have showed similar advantages for ECC training. One often cited mechanism for the greater advantage for ECC based training is the ability of ECC to produce greater maximal forces compared to maximal CON training (Farthing and Chilibeck 2003b; Roig et al 2009). Indeed, recent studies have indicated that when relative load is controlled, ECC may not be superior and that similar changes in muscle mass between ECC and CON may occur (Franchi et al., 2014, 2015). The importance of the ECC contraction in conventional training has also been highlighted. Hather et al. (1991) reported greater muscle fibre hypertrophy after training including both ECC and CON training compared to CON alone although other studies have reported increased muscle size utilizing protocols that included only CON training (Housh et al. 1996; Stock et al. 2017). English and colleagues (2014) added more weight to the lift during the ECC phase in order to take advantage of the increased force potential of ECC (known as accentuated ECC training) and found greater gains in muscle mass compared to a traditional loading protocol; although Walker and colleagues (2016) found no differences in muscle hypertrophy when comparing accentuated to conventional loading.

Comparisons of ECC and CON training with regards to strength have generated mixed results. With regards to isolated single contraction type training, ECC is more effective for increasing total overall strength (Farthing and Chilibeck, 2003b; Roig et al. 2009) but isolated ECC training is inferior for increasing CON strength as compared to CON training (Higbie et al. 1996; Hortobágyi et al. 1996; Seger et al. 1998; Roig et al. 2009). Results from conventional training involving both ECC and CON contractions indicate that accentuated ECC training is superior for increasing strength in comparison to traditional loading (English et al. 2014; Walker et al. 2016), and inclusion of a CON and ECC contraction compared to CON alone leads to greater increases in both CON and ECC (Colliander and Tesch, 1990) and averaged CON and

ECC (Lacerte et al. 1992) peak torque values. Overall, it appears that strength adaptations may be enhanced by effectively including or augmenting training with ECC contractions although issues regarding contraction type specificity of strength do come in to play and must be considered.

Together, these studies indicate potential for the inclusion of ECC training to maximize muscle hypertrophy and total strength but more research is needed to clarify exactly when and how ECC training might be most efficacious both during isolated ECC training and when combined with CON contractions. This thesis further explores this area, specifically investigating how ECC training with submaximal loads compares to more traditional supramaximal training and how varying the level of emphasis of the ECC phase affects strength and muscle hypertrophy during conventional iso-inertial training.

2.6 Limitations of Eccentric Training

As indicated above, inclusion and maximization of ECC training has potential to be highly advantageous for increasing both strength and muscle hypertrophy although these benefits do come with some notable downsides. Documentation of stiffness and soreness after ECC training dates back over 100 years (Hough, 1902). Intense ECC training is associated with decreased strength and delayed onset muscle soreness in the days following training sessions (Nosaka and Clarkson, 1996; Tokmakidis et al. 2003; Krentz and Farthing, 2010). Studies suggest muscle soreness occurs as soon as 6-8 hours after the bout of ECC exercise and eventually peaks around 48 hours post exercise (MacIntyre et al. 1995; Jones et al. 1997). Associated levels of soreness and decreased strength are often hypothesized to occur more profoundly after ECC training due to the higher forces associated with ECC contractions and subsequent sarcomere disruption (Shepstone et al. 2005). In accordance with the multiple deleterious effects, ECC training has often been viewed as unsuitable and potentially even dangerous for many novice or compromised lifters (e.g. young inexperienced lifters, older adults or those suffering from chronic diseases). Although muscle soreness is very common at the beginning of a new training program with or without ECC contractions, evidence suggests that soreness levels return to baseline within the first few weeks (Krentz et al. 2008). In fact, the risks and associations between unavoidable muscle damage and ECC training may be overstated (Baker and Cutlip, 2009). High intensity ECC training has inherent potential to be damaging but numerous studies support the idea that ECC training can be performed safely and with minimal muscle soreness when properly designed with gradual progression (LaStayo et al. 2007; Marcus et al. 2008). The studies in this thesis will investigate muscle soreness daily for the first 3 weeks of training to quantify differences in soreness that may exist between high and low intensity ECC training as well as training involving varying degrees of ECC contractions. Additionally, one goal of the thesis is to add to the growing body of knowledge regarding how best to implement ECC training with minimal deleterious side effects in the hopes that better designed ECC protocols may extend the applications of ECC training.

2.7 Supramaximal vs. Submaximal Eccentric Training

One major limitation to the accessibility of ECC training is the apparent requirement of supramaximal loading and subsequently the accompanying muscle soreness and temporary loss of function associated with these high forces during training. Related to this, an area that has only briefly been investigated is the use of submaximal ECC contractions. Nosaka and Newton (2002) reported that a bout of submaximal ECC contractions resulted in attenuated markers of muscle damage (isometric strength decline, swelling, decreased range of motion, and increased plasma creatine kinase) compared to a maximal ECC bout, and led to faster recovery. This research is important given the potential applications of ECC training to various populations (e.g. older adults) that may not respond well to supramaximal damaging ECC training. As well, submaximal loads may be more applicable as they may be less intimidating and do not necessarily require a spotter, as often required when using supramaximal loads. Further research is warranted to better determine the effectiveness of submaximal ECC training compared to supramaximal ECC training or matched intensity dual contraction CON/ECC training.

Hortobágyi and colleagues (1996) compared submaximal ECC training to a matched volume of CON training and showed that submaximal ECC training was more effective for increasing strength. No study has compared ECC and CON training of a matched intensity done to volitional fatigue. Roig and colleagues (2009) in their systematic review highlight the fact that much of the benefit of ECC training can be accounted for by the fact that ECC training can be performed at higher forces. This idea suggests that submaximal ECC training would be less effective than supramaximal ECC training. Conversely, Burd and colleagues (2010) suggest that a high intensity of contraction is not as important as performing exercises until volitional fatigue. This evidence suggests that submaximal training may be as effective as higher intensity ECC training if both are performed until failure.

To date, no study has directly investigated supramaximal versus submaximal ECC training performed until volitional fatigue and only one has compared high and low intensity isolated ECC training (Schroeder et al. 2004). Clearly more research is warranted on both the efficacy and potential application of submaximal ECC training. This thesis directly compares supramaximal versus submaximal ECC training on muscle hypertrophy, specific and nonspecific strength, ratings of perceived exertion and muscle soreness with the hopes of advancing the understanding of the potential application of submaximal ECC training.

2.8 Eccentric Training for Special Populations

The importance and potential superiority of ECC training with regards to muscle hypertrophy and strength has been well documented. Notably, ECC contractions have also been touted for their unique potential for some less obvious populations due to some distinctive characteristics. In addition to producing more absolute force than CON contractions, ECC contractions are also noted to be the most metabolically efficient. For a given amount of force produced ECC contractions have a lower oxygen cost (LaStayo et al. 1999; Meyer et al. 2003) and result in lower ratings of perceived exertion (Hollander et al. 2003) than CON contractions. Together, these characteristics make ECC training especially attractive for a number of clinical populations who may benefit from increased muscle hypertrophy and strength but may not be able to effectively induce these changes with higher load conventional training. ECC contractions have the potential to effectively and efficiently produce gains in strength and hypertrophy without stressing the cardiopulmonary system, ideal for populations with low exercise tolerance (Roig et al. 2008). Initial investigations have explored the utilization of ECC training for populations suffering from: cardiovascular disease (Steiner et al. 2004), COPD (Rooyackers et al. 2003), Parkinson’s disease (Dibble et al. 2006), stroke (Engardt et al. 1995), type 2 diabetes (Marcus et al. 2008, 2013) and osteoarthritis (Gur et al. 2002). Cancer survivors often suffer from cachexia (muscle weakness and muscle loss) which can lead to decreased mobility and ultimately lowered quality of life (LaStayo et al. 2014) although Hansen and colleagues (2009) report that survivors involved in an ECC strength program were able to increase both strength and mobility. ECC training may also be used effectively when recovering from orthopedic injuries. LaStayo et al. (2014) highlight the effectiveness of recovered mobility with ECC training in those who have had knee surgery (Gur et al. 2002).

The above list is by no means all-encompassing but does serve to shed light on the many potential applications of ECC training outside of elite level lifters' gains in muscle hypertrophy and strength. Since the foundational knowledge in the area of broader applicability and methodology of ECC training is somewhat lacking, the current thesis focuses on young healthy populations for all three included studies. That being said, some of the questions explored in this thesis regarding lower intensity ECC training and more practical, accessible ECC training methodology have shed light on advances in ECC training and subsequent broader applications. As well, the current thesis experiments monitor session RPE after training in all training groups in order to gain a better understanding of the perceived exertion associated with various forms and intensities of ECC training. These findings may have heightened relevance for clinical populations.

2.9 Modes of Implementing Eccentric Training

Conventional resistance training usually involves a CON and an ECC phase with loads almost exclusively limited by the strength of the CON phase for practical reasons (you must be able to lift the weight in order to do multiple repetitions). One of the first devices used to demonstrate the potential of ECC contractions involved two back to back bicycle ergometers (Abbott et al. 1952). From this setup, it became apparent that the person pedaling backward (eccentrically) could generate force much easier than the person pedaling forward (Abbott et al. 1952). Since those early studies and demonstrations, interest in ECC contractions has steadily grown. Eccentrically focused training is often more difficult to perform (and thus examine) and normally requires supervision or specialized equipment and / or creative exercise design (Isner-Horobeti et al 2013; Mike et al. 2015). Isokinetic dynamometers have the ability to control for contraction type and utilize a set angular velocity. Isokinetic dynamometry has allowed the direct comparison of CON and ECC contractions and knowledge gained through studies utilizing these devices have led us to the current dogma surrounding ECC training (Shepstone et al. 1985; Sale et al. 1987; Hortobáygi and Katch, 1990; Westing et al. 1990; Westing et al. 1991; Nosaka and Newton, 2002; Farthing and Chilibeck, 2003b; Krentz and Farthing, 2010). Additionally, isokinetic ECC training has been used with specific populations such as in athlete testing and training and in rehabilitation settings (Kellis and Baltzopoulos, 1995). Specifically, more recent advances in ECC ergometry involve motorized stepper-like devices that allow those with limited training ability to absorb the ECC force and perform low impact, safe ECC for rehabilitation purposes (for a detailed review see LaStayo et al. 2014). Undeniably, isokinetic machines have advanced the understanding of ECC contractions and their potential benefits and limitations. Unfortunately, their high cost and limited availability make everyday use of isokinetic ECC exercise unavailable to a majority of the population.

One method of targeted ECC training that has been shown advantageous involves adding extra weight to the ECC portion of the lift with the intent to better match the force generating potential of both CON and ECC contractions (Wagle et al. 2017; Suchomel et al. 2018). Studies have incorporated this type of accentuated ECC training utilizing specialized equipment (English et al. 2014; Walker et al. 2016) or using a spotter to add and remove weight (Brandenburg and Docherty, 2002). Accentuated ECC training is more effective for increasing strength (Walker et al. 2016; Suchomel et al. 2018) and muscle mass (English et al. 2016) than conventionally loaded resistance training. Similar to other iso-inertial loading techniques and isokinetic ECC exercise, accentuated ECC training requires a spotter and/or specialized equipment making it less practical than conventional iso-inertial training. Therefore, it is important to continue to develop and understand new ways to utilize accessible and easy to use equipment to incorporate ECC training.

Several ways to incorporate ECC training into iso-inertial exercise have been suggested (Mike et al. 2013). In a recent review, Suchomel et al. (2018) highlight these creative ways originally presented by Mike et al. (2015) but suggest that although each is theoretically feasible there is minimal research to support their effectiveness. These methods include such techniques as using two limbs to perform the CON and then only one limb to lower during the ECC, using supramaximal loads (greater than 100% CON), or extending the time spent performing the ECC phase of a conventional lift. These methods do have downsides though, including concerns about safety and exercise selection (not all exercises are easy or safe to perform with the 2/1 limb technique) and requirement of a spotter (especially needed during supramaximal loading). Extending or emphasizing the length of the ECC may be the most practical of these methods but to date limited research has been performed utilizing this method and those studies report mixed effectiveness (Gilies et al. 2005; Krentz et al. 2008; Dias et al. 2015).

One of the main objectives of this thesis is to add to the limited body of knowledge available regarding practical and accessible modes of ECC training. As such, all training in each of the three studies involves iso-inertial loading. In addition, study one explores the use of supramaximal compared to submaximal ECC training, study two provides further insights into the role that different degrees of ECC emphasis have when performing conventional iso-inertial training, and study three explores the relationship between contraction type and training intensity across both iso-inertial and isokinetic modalities. Ultimately, the knowledge gained in this thesis will lead to a greater understanding of both the practicality and effectiveness of ECC training utilizing conventional, iso-inertial methods as opposed to more commonly utilized forms of specialized equipment.

2.10 Eccentric Testing vs. Eccentric Strength Training

As mentioned above, a vast majority of the studies investigating ECC training have utilized non-conventional training and strength testing on devices such as isokinetic dynamometers (Higbie et al. 1996; Hortobágyi et al. 1996; Farthing and Chilibeck, 2003; Shepstone et al. 2005; Krentz and Farthing 2010). One weakness to this type of testing and training is the apparent disconnect that lies between these devices and real world applicable loading. There often exist unique motor learning strategies when performing isokinetic contractions that are distinct from iso-inertial or sport specific movements. Training performed with iso-inertial loading often does not lead to CON strength improvements when testing is then performed on an isokinetic device (Feiereisen et al. 2010; Lima et al. 2012; Gentil et al. 2017; Stock et al. 2017). Less is known about the transfer of strength between iso-inertial training and isokinetic ECC strength testing. Furthermore, very little information exists regarding the transfer of strength between iso-inertial training with different contraction types (ECC vs. CON) and of different intensities (high vs. low). The final study of this thesis aimed to investigate the adaptations resulting from iso-inertial training with special interest towards the interplay of contraction type and intensity, and how these variables alter adaptations in muscle hypertrophy, iso-inertial strength, and iso-kinetic strength.

2.11 Current Gaps in the Application of Eccentric Training

For all that is known about ECC contractions and for all the proposed potential benefits there are still several gaps when it comes to both studying and incorporating this type of training in everyday lifting. As outlined above, an overwhelming majority of the studies which have advanced our understanding of ECC training to date have been performed utilizing specialized equipment and /or involved high forces which are known to lead to prominent muscle soreness. Conversely, the proposed ECC training methods available that are most practical, safe, cost effective and easy to employ have garnered little research attention. This leaves the current state of ECC training research and practice theoretically advanced in understanding in laboratory settings, but lacking strong evidence to support methodologies that would be useful for the vast majority of people who could benefit from it. The goal of this thesis is to begin to change this by investigating the effectiveness of more accessible and applicable forms of ECC training. Specifically this thesis focused on three particular knowledge gaps: supramaximal versus submaximal ECC training, the importance and effectiveness of ECC emphasized training in conventional iso-inertial training, and the interplay of contraction type and training intensity on strength transferability across training and testing modalities.

Thesis Transition and Author Contribution – Study 1

As indicated in the literature review, two main goals of the thesis were to verify the effectiveness of iso-inertial ECC training as well as to investigate the effectiveness of submaximal ECC training compared to a more traditionally utilized supramaximal protocol. Both of these goals were accomplished in study one. By confirming the effectiveness of submaximal ECC training with iso-inertial loading, study one set the stage for the subsequent investigations in study two and three and also added valuable theoretical knowledge in the area of high vs. low intensity training for hypertrophy.

Contribution:

Joel Krentz was the lead contributor to this study and was involved in all aspects of the study including study design, participant recruitment, data acquisition, data analysis, and manuscript preparation. This manuscript has already been published and as indicated below Joel Krentz is the first author.

Published Manuscript Citation:

This manuscript has been published. The citation is as follows:

Krentz JR, Chilibeck PD, Farthing JP (2017) The effects of supramaximal versus submaximal intensity eccentric training when performed until volitional fatigue. Eur J Appl Physiol 117:2099-108.

* Note: This chapter includes some minor edits which differ from the actual published version of the manuscript

Chapter 3 – Study One

The effects of supramaximal versus submaximal intensity eccentric training when performed until volitional fatigue

3.1 Abstract

Purpose: Our purpose was to compare supramaximal versus submaximal intensity eccentric training performed until volitional fatigue.

Methods**:** 32 young adults (19 males) were randomized into one of 3 groups: 1) ECC110 performed eccentric (ECC) only with contractions at 110% of concentric (CON) 1–repetition maximum (1RM); 2) ECC80 performed ECC only contractions at 80% of CON 1RM; 3) a control group who did not specifically train their biceps but was encouraged to maintain their regular daily activities. Training progressed from 3 to 6 sets of unilateral ECC training of the elbow flexors over 8 weeks, with each set performed until volitional fatigue. Elbow flexors muscle thickness (via ultrasound) and 1RM were assessed pre and post training. Rating of perceived exertion (RPE) was recorded 30 minutes after each training session and muscle soreness was self-reported daily on the training arm for the first 3 weeks of training.

Results: Both ECC110 (+0.25 cm) and ECC80 (+ 0.21 cm) showed a greater post-training increase in muscle thickness compared to control (-0.01 cm) (p<0.05), with no differences between ECC110 and ECC80. ECC80 (+1.23 kg) showed a greater post-training increase in strength compared to control (p<0.05), while ECC110 (+0.76 kg) had no significant difference post-training vs. control (-0.01 kg). ECC80 had significantly lower average RPE scores than ECC110 (p<0.05).

Conclusions: Both supramaximal and submaximal intensity ECC training are effective for increasing muscle size but submaximal ECC training is perceived to require less exertion than supramaximal training. These findings suggest that submaximal ECC training may be an ideal strategy to increase muscle size and strength in individuals whose needs warrant training at a lower level of exertion.

3.2 Introduction

The pursuit of optimal muscle hypertrophy has long been investigated during adaptations to resistance training and remains a controversial and popular topic for physiology and exercise scientists. Populations ranging from advanced and elite lifters to clinical populations suffering from disuse atrophy or disease cachexia (Roig et al. 2008) may all benefit from training protocols leading to increased muscle mass. Well known and generally accepted training prescriptions (Ratamess et al. 2009) [America College of Sports Medicine Positions Stand] suggest muscle hypertrophy is optimized using moderate to heavy loads; 70-85% of one repetition maximum (1 RM) for novice and intermediate and 70-100% 1 RM for advanced lifters. These different training recommendations recognize that responses to muscle hypertrophy may be affected by the training status of the lifter. Lifters who are untrained exhibit longer lasting and greater overall muscle protein synthesis rates following training sessions compared to those classified as trained (Damas et al. 2015) although less is known about the relationship between training status, training intensity and chronic muscle hypertrophy. Recent topical reviews focusing on training intensity and muscle hypertrophy suggest much less clarity in this area and summarize evidence on the efficacy of both high and low load training prescriptions for muscle hypertrophy (Fisher et al. 2013; Schoenfeld et al. 2016; Fisher et al. 2017).

A number of studies have shown no differences in training-induced muscle hypertrophy when comparing higher versus lower intensity resistance training protocols (Hisaeda et al. 1996; Chestnut et al. 1999; Tanimoto et al. 2006; Mitchell et al. 2012; Alegre et al. 2015). Burd and colleagues (2010) report that protein synthesis is stimulated more with low load resistance (30% 1 RM) than high (90% 1RM) when both intensities are performed to failure. In explaining their findings, Burd et al. suggest that performing contractions to volitional fatigue (i.e. failure) is more important than the intensity of contraction for activating all motor units, including the high threshold type II fibers. Other studies maintain that lower intensity training remains inferior to high intensity for muscle hypertrophy (Campos et al. 2002; Holm et al. 2008; Schuenke et al. 2012). To date, no investigation has compared hypertrophic adaptations after high versus low intensity ECC (i.e. lengthening) training to volitional fatigue. This gap in the literature is noteworthy considering the evidence that eccentrically emphasized training generally leads to greater gains in strength and muscle hypertrophy compared to CON (shortening) training (Higbie et al. 1996; Seger et al. 1998; Hortobágyi et al. 1996; Farthing and Chilibeck, 2003b).

Torque-velocity curves indicate that greater force is produced during ECC contractions in comparison to CON contractions (Sale et al. 1987; Hortobáygi and Katch, 1990; Westing et al. 1990; Westing et al. 1991; Farthing and Chilibeck, 2003b). Intuitively when the ECC portion of a conventional lifting exercise is emphasized, training can be performed at levels that are greater than 100% of an individual’s CON 1-RM (known as supramaximal ECC training). A systematic review by Roig and colleagues (2009) examined the issue of ECC versus CON training and concluded that ECC training, when performed at a higher intensity than CON training, was more effective for increasing total strength and muscle mass. They suggested that the superiority of ECC training was likely mediated by the ability of such contractions to produce greater forces during training. Farthing and Chilibeck (2003) also proposed the idea that the efficacy of ECC training results from the ability to train with greater intensity than CON training. Other studies have matched for volume (Hortobágyi et al. 1996) or work (Moore et al. 2005) and reported inherent advantages of ECC contractions over CON contractions.

For a given amount of force produced, ECC contractions have a lower oxygen cost (LaStayo et al. 1999; Meyer et al. 2003) and lower ratings of perceived exertion (Hollander et al. 2003) than CON contractions. Intense ECC training is associated with decreased strength and an increase in delayed onset muscle soreness in the days following training sessions (Nosaka and Clarkson, 1996; Tokmakidis et al. 2003; Krentz and Farthing, 2010). This is likely due to a combination of factors including higher force production during ECC training and sarcomere disruption specifically associated with lengthening contractions (Shepstone et al. 2005). Submaximal intensity ECC training has been reported to show less deleterious effects than maximal ECC training (Nosaka and Newton, 2002) and past research on training intensity suggests that training with lower intensities may lead to greater exercise adherence (Perri et al. 2002). Optimization of minimally damaging and lower exertional ECC training protocols is important in the continued application of ECC training to a wide variety of individuals, especially clinical populations (e.g. COPD, type 2 diabetes).

To our knowledge, no research has compared muscle hypertrophy and strength adaptations in response to submaximal versus supramaximal ECC training when both are performed until volitional fatigue. The purpose of this investigation was to compare supramaximal versus submaximal intensity ECC training performed until volitional fatigue. The primary hypotheses were that supramaximal ECC training would be superior to submaximal ECC training for increasing CON strength and that both types of ECC training would significantly increase muscle size compared to control. Due to the limited evidence available, it was difficult to predict which intensity of ECC training would yield superior muscle hypertrophy but original concentric-focused work in this area (Burd et al. 2010) suggests that low loads performed to failure may be superior due to greater overall training volume. The secondary hypothesis was that higher intensity (supramaximal) ECC training will result in higher ratings of perceived exertion and greater muscle soreness than lower intensity ECC training.

3.3 Methods

3.3.1 Participants

Ethical approval for the study was obtained from the University of Saskatchewan Biomedical Ethics Review Board, and all participants gave informed written consent before participating. A total of 44 (22 male) participants were initially enrolled in the study and completed the pre-testing procedures. Young healthy males and females with varied training experience (Appendix A) were included to allow for greater generalizability, and because many studies have shown similar time course of adaptation across sexes (Cureton et al. 1988; Staron et al. 1994; Abe et al. 2000, Krentz and Farthing, 2010). Once enrolled, participants were asked to continue their regular exercise regime and, if assigned to one of the training groups, to refrain from any additional targeted training of the elbow flexors aside from that prescribed in the study. Participant characteristics are outlined in Table 3.1.

3.3.2 Study Design

The study utilized a between subjects design consisting of pre and post testing after 8 weeks of unilateral elbow flexors concentration curl resistance training. Upon completion of the pre-testing session participants were randomized to one of three groups (ECC110 performed ECC only contractions at 110% of CON 1–repetition maximum (1RM), ECC80 performed ECC only contractions at 80% of CON 1RM, or a control group that did no training) in a counterbalanced fashion using a random number generator (www.random.org), with stratification by sex. All measurements were taken in the same order for each participant on pre- and post-intervention visits. Specifically, participants' dominant arm (self-reported) muscle thickness was measured first followed by CON dumbbell 1RM of that same arm.

During the eight weeks of training, CON concentration curl 1RM was reassessed at the start of weeks 3 and 6. Monitoring of 1RM during the study allowed for adequate prescription of ECC training intensities according to each participant's individual progression in CON 1RM strength.

3.3.3 Training programs

All training groups performed dominant limb unilateral training of the elbow flexors (i.e. concentration curls) to volitional fatigue using iso-inertial ECC loading (i.e., dumbbell hand-held weights) where the load was lowered uniformly through the full range of motion for three seconds. Volitional fatigue was defined as the point where the participant could no longer control the resistance for the full three-second phase of the movement or through the full range of motion. The non-dominant limb was used to assist the dominant limb during performance of the CON portion of the lift. The training period of the study lasted 8 weeks and involved progressive

Table 3.1 Participant Characteristics

	ECC110 (n=8 5M:3F)	ECC80 (n=9 7M:2F)	Control * (n=15 7M:8F)
Age (y)	26.3 ± 6.7	23.3 ± 7.4	21.7 ± 3.2
Height (cm)	174.2 ± 9.7	175.9 ± 8.0	170.4 ± 10.0
Weight (kg)	74.6 ± 12.8	74.2 ± 11.1	68.6 ± 11.6
Training Experience (months)	31.5 ± 20.1	21.4 ± 26.3	17.6 ± 15.8

All data in table is mean ± standard deviation.

*Unequal participant numbers across groups due to moderate rates of dropout in the training groups which did not occur in the control group. Seven individuals from the ECC110 group and five from the ECC80 withdrew from the study.

overload. Participants started their first training session by completing 3 sets of their assigned contractions to volitional fatigue. The training progression then continued by adding one set to each training session until participants reached 6 sets. Rest between sets was two minutes. Past research from our lab has shown that intense training eccentrically every second day for 20 days using a dynamometer resulted in reduced strength and general overtraining (Krentz and Farthing, 2010). For this reason, participants trained 2 sessions a week with at least 72 hours rest in between sessions for the first 2 weeks and then progressed to 3 training sessions a week for the final 6 weeks of the study. If a participant was able to perform more than 20 repetitions for all prescribed sets, they were instructed to increase the training weight for the next training session. However, this increase was only prescribed if the increased training load still remained within 10% of the prescribed training intensity for that group (110% or 80% 1RM). Additionally, if participants were not able to perform at least 4 repetitions for all prescribed sets, the training weight was lowered for the next training session. As above, this decrease was only permitted if the load remained within 10% of the assigned training intensity. These practical modifications allowed for training to be performed until volitional fatigue during all sessions while ensuring that training was performed within the prescribed repetition ranges (ie. 8-12) appropriate for optimally increasing both strength and hypertrophy (Ratamess et al. 2009). At the completion of the training phase, participants were given a minimum of 72 hours rest before completing the post testing session to ensure full recovery.

3.3.4 Measures

3.3.4.1 Muscle Thickness

Muscle thickness of the dominant elbow flexors was measured before and after the 8 weeks training period using B-mode ultrasound (LOGIQ e BTO8, GE Healthcare, Milwaukee, Wisconsin, USA) according to our previous methods (Farthing et al. 2005; Krentz and Farthing, 2010). The coefficient of variation for this technique for elbow flexors is 2.14% (Krentz and Farthing, 2010).

Muscle thickness measures always preceded strength measures to avoid the confounding effects associated with transient muscle edema. Elbow flexor muscle thickness was taken on the midline of the biceps brachii muscle belly between the medial acromion and the fossa cubit, approximately 1/3 of the distance away from the fossa cubit. Once this point was established a detailed land marking procedure (using overhead transparencies) was employed to ensure exact placement of the ultrasound probe pre and post training (Farthing and Chilibeck, 2003a; Krentz and Farthing, 2010). Four measurements were taken and the averages of the two closest measurements (to each other) were used to calculate the muscle thickness value.

3.3.4.2 Iso-inertial Maximal Strength Testing

Iso-inertial strength of the elbow flexors of the dominant arm was assessed using a maximal unilateral CON concentration curl. Briefly, a concentration curl is a movement where, in a seated position, one arm is rested against the upper thigh for support and the elbow flexors are used to lift a dumbbell (Figure 3.1). Participants were instructed to lift the weight off the ground vertically and then pause briefly before attempting the actual lift. Instructions were given to lift the weight in a controlled fashion without leaning their upper body back or other postural compensations.

Prior to beginning maximal lifts, participants were given a light weight to perform 1-2 warm-up sets. Participants then attempted a weight they were confident they could lift. Participants then rested before performing the next weight (approximately 2-3 minutes). One repetition maximum was determined as the highest weight that could be successfully lifted one time.

3.3.4.3 Muscle Soreness

Muscle soreness of the dominant arm was tracked daily the first 3 weeks of the study using a visual analog scale (VAS) (Appendix D), where participants indicated their degree of muscle soreness from 0 to 100 by making a mark on a 100mm horizontal line on paper. Muscle soreness was monitored only for the first 3 weeks of the study, since our previous research suggests soreness peaks within the first few weeks of training and then decreases to near zero (Krentz et al. 2008). Soreness scores were recorded after completing a standard movement, involving first lengthening and then shortening (contracting) the biceps in a slow controlled manner. When reporting soreness on a training day, participants were instructed to always record soreness prior to the training session.

Figure 3.1 Concentration Curl Set-up

3.3.4.4 Ratings of Perceived Exertion

All participants were instructed to record a session RPE score in their training log (Appendix C) upon completion of training each day, using a modified session RPE scale (Foster et al. 2001; McGuigan and Foster, 2004) (Appendix E). The scale ranges from 1 to 10, with accompanying verbal descriptions of each numerical rating. Participants were instructed to wait 30 minutes after the training session and then used this scale to indicate a composite RPE for the training session based on the question “How was your workout?” (McGuigan and Foster, 2004). This RPE scale has been reported as a valid measure of both aerobic and anaerobic exercise (Foster et al. 2001). Specific to resistance training, session RPE is a valid (Sweet et al. 2004) and reliable (Day et al. 2004; McGuigan et al. 2004) monitoring tool.

3.3.4.5 Volume Load

All participants were instructed to record the number of repetitions completed and load utilized during each set of training (Appendix C). From this data, average volume load per training session was calculated. Volume load was calculated by multiplying the total number of repetitions completed by the training load (kg) for each training session (McBride et al. 2009). All completed training sessions were tallied and then the total volume load was divided by the total number of possible training sessions for each participant (22 total sessions) to calculate an average volume load per training session.

3.3.5 Data Analysis

Data distributions were tested for statistical assumptions of normality before proceeding with further omnibus tests. All data analyses were performed with IBM SPSS, version 22 for Windows. Post-training muscle thickness and CON 1RM iso-inertial strength were assessed via MANCOVA for two dependent measures, and using pre-training values as covariates. MANCOVA was followed by univariate ANCOVA when appropriate for each of the variables. Muscle soreness and RPE were analyzed separately using 2 way (group [ECC110, ECC80] × time [cumulative weekly score for week 1, week 2, week 3 for muscle soreness; average daily score for weeks 1+2, weeks 3+4, weeks 5+6, weeks 7+8 for RPE]) repeated measures factorial ANOVA. Simple effects analysis and post hoc multiple comparisons (adjusted for familywise error) were performed when appropriate. Volume load was analyzed using an independent t-test to examine potential differences between the two training groups (ECC110, ECC80). Effect size was calculated for MANCOVA and ANCOVA. Effect size values are generally accepted as follows: 0.1 = small, 0.3 = medium, 0.5 = large (Cohen, 1992). Significance was set at $p<0.05$. In the case of missing data points resulting from missing training and/or soreness logs (self-reported RPE, muscle soreness, and volume load) only completer data was used for analysis.

3.4 Results

3.4.1 Final Group Enrollment

Of the 44 participants initially enrolled, 32 completed the study. Details of those who withdrew were as follows: ECC110 two males, five females; ECC80 one male, four females. Reasons for withdrawal were as follows: ECC110: three due to time, two due to soreness and pain, two undisclosed; ECC80: four due to time, one undisclosed.

3.4.2 Muscle Thickness and Strength

MANCOVA revealed a significant group effect (Pillai's Trace = 0.549, F (4,54) = 5.114, p<0.01). Univariate ANCOVA revealed a significant group effect for muscle thickness (F (2,27) = 9.09, p<0.01 partial η^2 = .402. Pairwise comparisons on post-training means, adjusted for familywise error (p<0.05/3) revealed that both ECC110 (3.82 cm) and ECC80 (3.78 cm) were significantly greater than Control (3.56 cm) (p<0.01). There was no significant difference between ECC110 and ECC80 (Figure 3.2).

Univariate ANCOVA for strength revealed a significant group effect (F (2,27) = 5.70, p<0.01 partial η^2 = .297). Pairwise comparisons on post-training means, adjusted for familywise error revealed that ECC80 (16.9 kg) was significantly greater than control (15.7 kg) (p<0.01) but not different than ECC110 (16.4 kg). There was no significant difference between ECC110 and control (Figure 3.3).

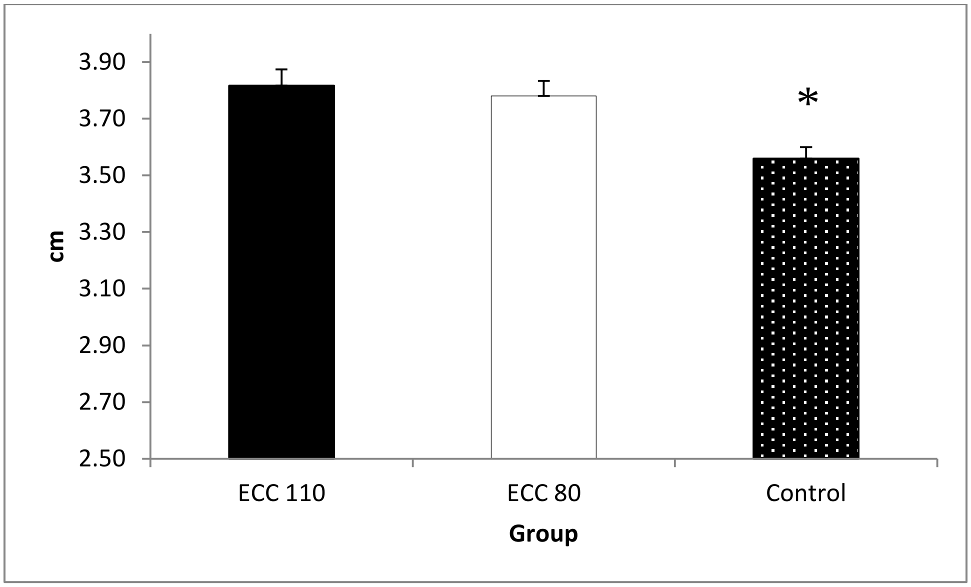


Figure 3.2 Muscle thickness values compared to a covariate adjusted pre-value of 3.57cm. * Indicates significantly different than both ECC110 ($p<0.01$) and ECC80 ($p<0.01$).Values are means ± SEM

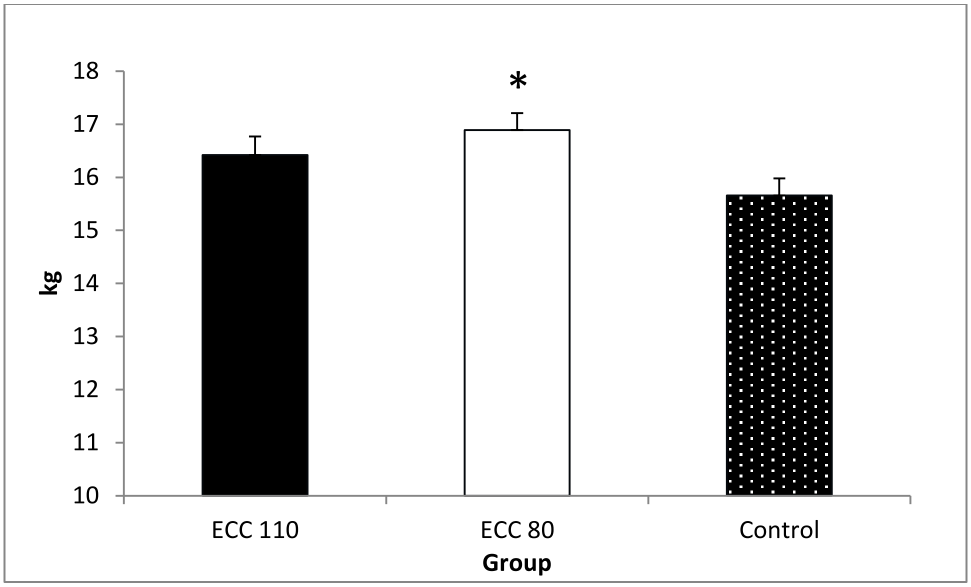


Figure 3.3 Strength values compared to a covariate adjusted pre-value of 15.7 kg. * Indicates significantly different than Control (*p*<0.01). A non-significant trend (*p*=0.065) was present for ECC110 different compared to control. Values are means ± SEM

3.4.3 Volume Load

Upon completion of the study, participants were instructed to hand back completed training logs in order to analyze volume load. Unfortunately, not all participants handed back completed log books. For calculation and analysis of volume load, only completer data were used (n=5 for ECC110, n=8 for ECC80). Results of the independent t-test indicated no significant differences for average volume load per training session between ECC110 and ECC80, t (11) = -0.972, p=0.352 (Figure 3.4). It should be noted that use of completer data for analysis due to missing data points could be a limitation if the completer data was not representative of the entire group. As a check of completer data, additional analysis was performed in which group means were imputed for each missing data point. Results of this analysis were not different than when only completer data was used.

3.4.4 Muscle Soreness

Similar to volume load, not all muscle soreness logs were returned for analysis therefore only completer data was used for analysis (n=6 for ECC110, n=8 for ECC80). Results of the omnibus ANOVA revealed a significant main effect of time Greenhouse-Geisser (GG), (F (1.10,13.18) = 14.98, p<0.01). Soreness decreased from week 1 to week 3 (p<0.01; Figure 3.5). There was no significant main effect of group and no group × time interaction (p=0.364). Additional analysis was completed in which group means were imputed for each missing data point and the results of this analysis were not different than when completer data was used.

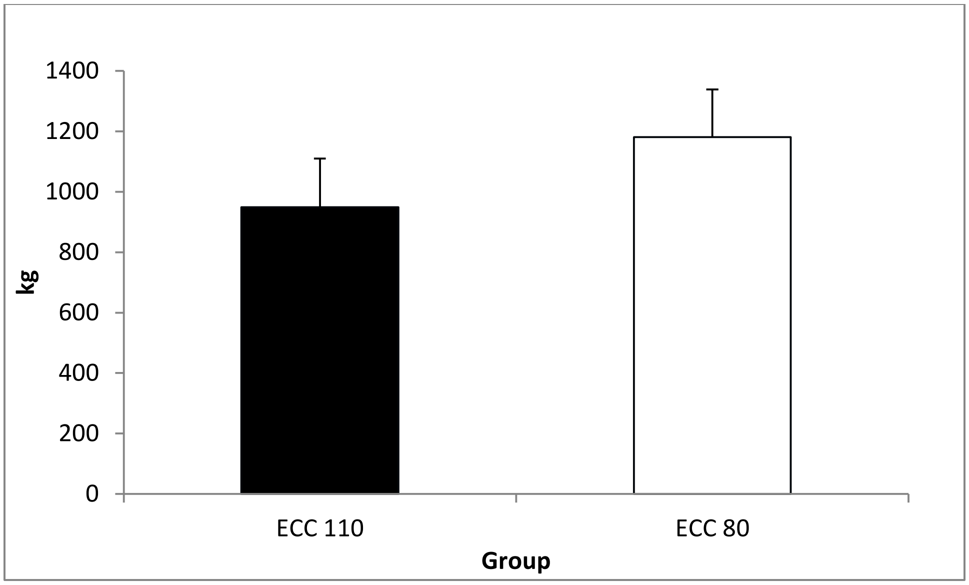


Figure 3.4 Average volume load per training session. Values are means ± SEM

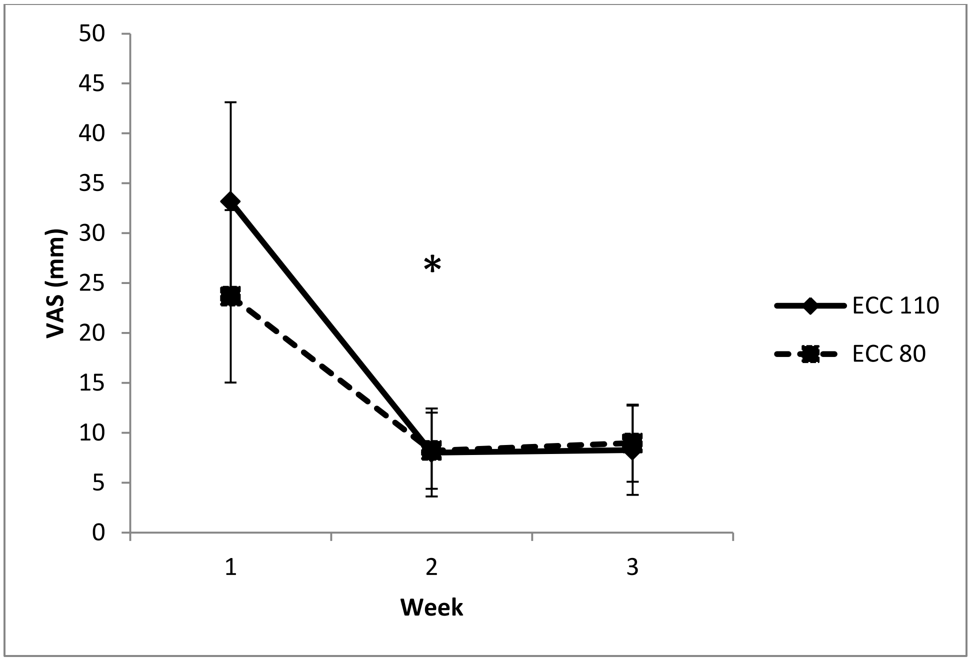


Figure 3.5 Cumulative Weekly Muscle Soreness. * Indicates significant main effect of time pooled across groups (p<0.01).Values are means ± SEM

3.4.5 Ratings of Perceived Exertion (RPE)

In line with volume load, not all training logs containing RPE were returned for analysis therefore only completer data was used for analysis (n=5 for ECC110, n=8 for ECC80). Results of the 4 (bi-weekly) x 2 (group) repeated measures factorial ANOVA for RPE indicated a significant main effect of group, F (1,11) = 6.70, $p<0.05$. There was no significant main effect of time and no significant group × time interaction ($p>0.05$). RPE was significantly lower for ECC80 throughout the study (Figure 3.6). Additional analysis was completed in which group means were imputed for each missing data point and the results of this analysis were not different than when only completer data was used.

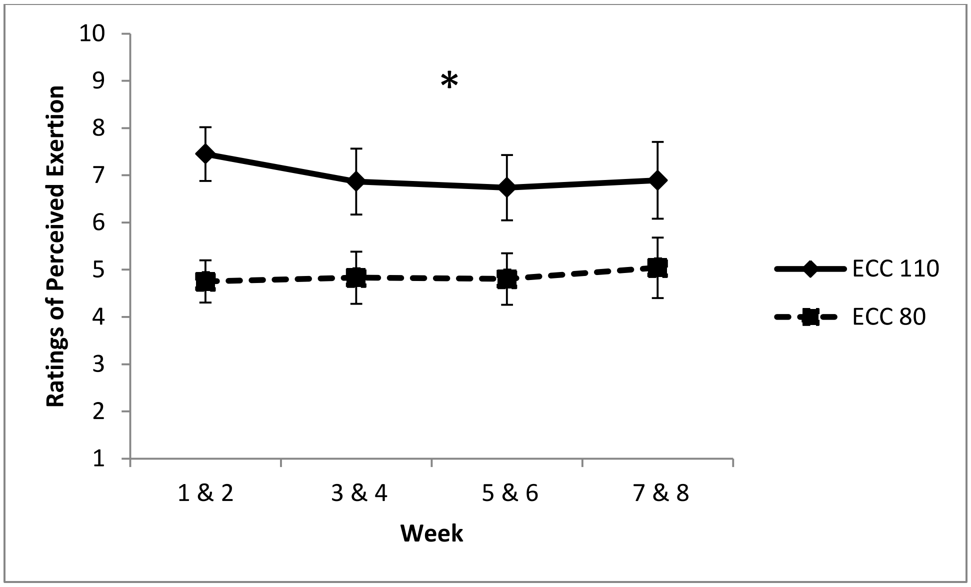


Figure 3.6 Biweekly Ratings of Perceived Exertion. * Indicates ECC110 significantly different than ECC80, averaged across all weeks (*p*<0.05).Values are means ± SEM

3.5 Discussion

The main finding of our study is that both supramaximal (ECC110) and submaximal (ECC80) intensity ECC training resulted in equal gains in muscle hypertrophy (Figure 3.2) but that submaximal intensity training resulted in significantly lower self-reported ratings of perceived exertion (Figure 3.6) and was the only training method of the two tested to result in greater increases in strength compared to control. The role of training intensity in resistance training has gained popularity in the literature and led to significant scientific investigation and debate. Though many studies have contributed to this discussion (Hisaeda et al. 1996; Chestnut et al. 1999; Tanimoto et al. 2006; Burd et al. 2010; Mitchell et al. 2012; Alegre et al. 2015; Jenkins et al. 2015; Schoenfeld et al. 2015), the present study is the first to do so comparing eccentrically emphasized training. These findings suggest submaximal intensity ECC training may be an effective alternative to more commonly prescribed supramaximal ECC training due to its ability to produce similar gains in muscle size while requiring less exertion to perform.

Our findings of similar muscle hypertrophy between supramaximal and submaximal intensity training groups are congruent with several studies which have investigated high vs. low intensity CON training (Hisaeda et al. 1996; Chestnut et al. 1999; Tanimoto et al. 2006; Mitchell et al. 2012; Ogasawara et al. 2013; Alegre et al. 2015; Schoenfeld et al. 2015; Jenkins et al. 2016). An important commonality between the current study and many previous studies is training-induced fatigue. This has been accomplished in other studies through performance of equal reps with longer time under tension (Tanimoto et al. 2006) or more commonly by performing repetitions until volitional fatigue for each set (Mitchell et al. 2012; Ogasawara et al. 2013; Schoenfeld et al. 2015; Jenkins et al. 2016). In the current study, participants performed repetitions until volitional fatigue as defined by successful completion of ECC repetitions.

Although completed repetitions were free to vary between ECC110 and ECC80, there was no significant difference between the training groups for average volume load per training session (Figure 3.4). Our results support the proposition that training to failure may be more important for muscle hypertrophy than the intensity (relative to 1RM) of a given training session (Burd et al. 2010) and, to our knowledge we are the first to extend this idea to eccentrically emphasized training protocols.

The finding that lower intensity training resulted in similar gains in muscle size (Figure 3.2) with a lower rating of perceived exertion (Figure 3.6) has important clinical ramifications. One reason for the renewed interest in high vs. low intensity resistance training outcomes is related to the limited accessibility of high intensity training in recreational and clinical settings. Literature from the American Heart Association (Williams et al. 2007) suggest that high intensity training may be contraindicated for certain clinical populations. It has previously been established that ECC contractions result in lower ratings of perceived exertion (Hollander et al. 2003) and lower oxygen cost per unit of force (LaStayo et al. 1999; Meyer et al. 2003) than CON contractions, leading to suggestions that ECC training may be beneficial for a number of clinical populations in which high exertion levels may be contraindicated (Roig et al. 2008). This application of ECC training may be promising for individuals suffering from a number of chronic health conditions including cardiovascular disease (Steiner et al. 2004), COPD (Rooyackers et al. 2003), Parkinson's disease (Dibble et al. 2006), stroke (Engardt et al. 1995), and type 2 diabetes (Marcus et al. 2008). The current findings that low intensity ECC training is as effective for muscle hypertrophy with lower RPE than high intensity training supports this type of training as a good fit for clinical populations who may benefit from increased muscle mass but may not be able to train with maximal intensities. Additionally, lower adherence rates have been reported for higher intensity training programs in healthy populations (Perri et al. 2002) suggesting that lower intensity resistance training may enhance adherence and ultimately greater long term training outcomes.

Although numerous studies have reported equally effective muscle hypertrophy between high vs. low intensity CON training, increases in strength have favoured more traditionally prescribed high intensity training programs (Rana et al. 2008; Mitchell et al. 2012; Schoenfeld et al. 2015). As such, we hypothesized that high intensity ECC training would be more effective for increasing strength than low intensity ECC training. Contrary to this, our results show only the ECC80 group significantly increased 1RM when compared to the control group (Figure 3.3); although there was also a trend for ECC110 to exceed control (p=0.065). It is important to note that although only the ECC80 group showed a significant improvement over the control group, the actual difference between the post testing strength in the two training groups was quite small (0.5 kg). ECC110 increased strength by approximately 4.8% compared to the baseline covariate, whereas ECC80 increased ~7.8%. Two main differences exist between the current study and others comparing high vs. low intensity training strength. The current study had participants train eccentrically but then test strength with a CON 1RM. This was done primarily due to the difficulty of reliably estimating one's ECC 1RM with iso-inertial loads and due to the more practical and applied nature of a CON 1RM. This contrasts with other studies that both trained and tested concentrically (Rana et al. 2008; Mitchell et al. 2012; Schoenfeld et al. 2015). Importantly, other studies that monitored strength utilized training intensities as low as 30% of 1RM (Mitchell et al. 2012), which may not be optimal for increasing muscular strength compared to higher intensities. In the current study, the lowest intensity group (ECC80) trained at 80% of CON 1RM; an intensity deemed high in conventional training settings and commonly prescribed for increasing strength (Ratamess et al. 2009). This may explain why the low intensity ECC training group in the current study (ECC80) was slightly more effective for increasing CON strength, a finding not consistent with other studies reporting higher intensity training more effective (Mitchell et al. 2012; Schoenfeld et al. 2015).

An important consideration with eccentrically emphasized training is the potential for muscle damage and associated muscle soreness. Intense ECC training is commonly associated with decreased strength and delayed onset muscle soreness in the first few days after training (Nosaka and Clarkson, 1996; Tokmakidis et al. 2003; Krentz and Farthing, 2010). The current investigation found no significant differences between ECC80 and ECC110 with regards to self-reported muscle soreness. This contrasts with past research where indicators of muscle damage were smaller and recovery was faster with submaximal vs. maximal ECC loading (Nosaka and Newton, 2002). This is likely explained by the fact that the current study had both groups training until failure while the past study by Nosaka and Newton (2002) had each group perform 3 sets of 10 repetitions, resulting in less total work for the lower intensity group. High intensity ECC training has inherent potential to be damaging but past research supports the idea that ECC training can be performed safely and with minimal damage (LaStayo et al. 2007). Although the current investigation did not indicate lower intensity training as being more effective for reducing muscle soreness, it is congruent with the idea that well-designed and progressive ECC training programs of high or low intensities can be well tolerated. Group soreness was elevated during the initial week of training but significantly decreased in the subsequent two weeks it was monitored (Figure 3.5). The benefits of low intensity ECC training reported in the current investigation highlight the need for future studies to continue to investigate the relationship between muscle damage, muscle soreness, and varying intensities of ECC training.

In conclusion, the current study is the first to compare supramaximal vs. submaximal intensity eccentrically emphasized resistance training performed until volitional fatigue and adds to the growing literature focused on conventional (CON) training. Although less commonly employed, ECC training has well-documented advantages for muscle hypertrophy and may be of particular interest and benefit to a subset of clinical populations. The results provide further support and optimism for this idea, reporting equal increases in muscle hypertrophy after submaximal or supramaximal intensity ECC training. These results are especially noteworthy considering that lower intensity training was perceived as easier. As a caution, the current study utilized only a single movement (arm curl) and focused on one body joint (elbow flexors). Future studies should seek to replicate and advance these experiments with other muscles groups and/or include full body investigations. Additionally, the current study did not control for training status of the participants which may have influenced potential adaptations between those more or less well trained. Future studies may seek to isolate a particular stratification of the training population to better understand how submaximal and supramaximal ECC training affect specifically those who are well trained or those who are untrained. Stratification by training experience before randomization may also eliminate the need to use covariate based analysis as was required in the current study to accommodate for large variation in baseline values between participants. Another notable limitation of the current study was the large number of participant withdrawals. Although lack of time to train was the most commonly cited reason for withdrawal, ECC training programs are only truly effective if they are chronically tolerable for those engaging in the training. Future research should continue to monitor the rate of withdrawal when prescribing ECC training and the pursuit of more accessible, better tolerated ECC training protocols will continue to be an area of importance. Note that although the results may seem promising for a range of populations, the current study involved only young healthy adults. Future research should seek to extend these results to clinical populations that may benefit from low intensity ECC training.

Conflicts of Interest: The authors declare that they have no conflict of interest

Thesis Transition and Author Contribution – Study 2

Study one provided important theoretical information surrounding the main finding that submaximal eccentric training was as effective as supramaximal training and that isolated eccentric training with dumbbells could be performed safely and effectively. But, isolated eccentric training may not be as practical or desirable to many individuals as conventional lifts that involve both a concentric and eccentric phase. For this reason, study 2 was designed to explore the influence of varying the time of eccentric emphasis during conventional, concentric based lifting with the goal of investigating ways to emphasize the ECC phase of training in conventional concentric focused lifts.

It should be noted that the control group for study two is the same group of individuals as the control group from study one. Data collection for all groups took place over a two year period in which counterbalanced randomized recruitment occurred for all seven groups. This was done both for practicality and to attempt to have equal conditions and equal group numbers across all groups intended for the thesis. It was never the plan to compare all seven groups in one large study. Rather, it was agreed upon during the study planning phase that for studies which would require a repeated group (ex. a control group) it would be most efficient to utilize that same group in multiple studies rather than re-recruit a new group of individuals to undergo the exact same study conditions.

Contribution:

Joel Krentz was the lead contributor to this study and was involved in all aspects of the study including study design, participant recruitment, data acquisition, data analysis, and manuscript preparation. This manuscript has not yet been submitted for publication but when it is Joel Krentz will be the first author.

Chapter 4 – Study Two

Muscle hypertrophy and strength responses to iso-inertial training with eccentric emphasis

4.1 Abstract

Purpose: Our purpose was to compare muscle hypertrophy and strength among groups utilizing conventional training (concentric with a standard lowering), concentric only contractions, and concentric contractions with an emphasized (3 second lowering) eccentric contraction.

Methods**:** 52 (28 male) participants were randomized into one of 4 groups: 1) CON80 (n=10) performed concentric (CON) only contractions at 80% of CON 1–repetition maximum (1RM); 2) CON/ECC80 (n=13) performed a CON contraction followed by a 3 second long emphasized eccentric (ECC) contraction at 80% of CON 1RM; Conventional 80 (n=14) performed conventional CON contractions with a traditional self-paced ECC contraction at 80% of CON 1RM; or a non-training control group (n=15). Training progressed from 3 to 6 sets of unilateral elbow flexors over 8 weeks. Elbow flexor muscle thickness (via ultrasound) and CON 1RM were assessed pre and post training. Ratings of perceived exertion (RPE), self-reported muscle soreness, and per session training volume were collected for each group.

Results: Change in muscle thickness, was significantly greater for CON/ECC80 (4.4%) than both CON80 (-0.3%) ($p<0.05$) and Control (-0.7%) ($p<0.05$) but not Conventional 80 (2.0%) ($p>0.05$). For strength change, all training groups, CON80 (16.0%) ($p<0.001$), CON/ECC80 (14.3%) ($p<0.001$) and Conventional 80 (19.3%) ($p<0.001$) were significantly different than

Control (-0.7%). There were no significant differences between training groups for muscle soreness, RPE, or average training volume per session (*p*>0.05 respectively).
Conclusions: Iso-inertial CON training with an emphasized ECC component (CON/ECC80) was the only training intervention to show greater muscle hypertrophy compared the control group (Figure 4.2) but all three training groups demonstrated similar increases in CON strength (Figure 4.3) The results highlight the importance of the ECC portion of the lift during conventional iso-inertial training in order to maximize gains in both strength and muscle hypertrophy.

4.2 Introduction

Optimization of training requires the strategic manipulation of a number of programming specific variables (Kraemer & Ratamess 2004; Ratamess et al. 2009; Schoenfeld et al. 2015). Within these variables, utilization of the ECC component of a contraction is a potentially advantageous yet often overlooked aspect of prescription. Conventional resistance training involves both a CON portion and an ECC portion. As ECC strength capability is substantially greater than CON (Sale et al. 1987; Hortobáygi and Katch, 1990; Westing et al. 1990; Westing et al. 1991; Farthing and Chilibeck, 2003), conventional iso-inertial resistance training predominantly overloads the CON portion. Therefore, the intensities utilized during conventional training are often both prescribed for, and limited by, CON strength.

Isolated ECC training generally leads to greater gains in muscle hypertrophy than isolated CON training (Higbie et al. 1996; Seger et al. 1998; Hortobágyi et al. 1996; Farthing and Chilibeck, 2003b; Vikne et al 2006; Roig et al. 2009) and is typically more effective for increasing total overall strength (Farthing and Chilibeck, 2003b; Roig et al. 2009). However, while the ECC component of training appears important for driving larger adaptations, ECC training is not without limitations. In accordance with the principle of specificity, isolated ECC training is inferior in its ability to increase CON strength as compared to CON training (Higbie et al. 1996; Hortobágyi et al. 1996; Seger et al. 1998; Roig et al. 2009). As well, intense ECC training can be associated with acute decreases in strength and an increase in delayed onset muscle soreness (Nosaka and Clarkson, 1996; Tokmakidis et al. 2003; Krentz and Farthing, 2010). Most training equipment is built to incorporate both a CON and an ECC contraction, leaving isolated ECC training difficult to perform without additional supervision. Additionally, most of what is known about ECC training has emerged from studies using isokinetic dynamometry (See review, Isner-Horobeti et al. 2013), leaving a large knowledge gap on training outcomes more specific to the way most individuals train in a practical or clinical setting.

Conventional training incorporating an *accentuated* load during the ECC component (i.e. increasing the load or resistance for the ECC phase) has been studied with regards to strength and muscle hypertrophy. English and colleagues (2014) examined training with constant intensity CON training and varying intensities of ECC training. Results of their study concluded that only overloaded ECC training resulted in increased muscle mass and was more effective than traditional or underload ECC training for increasing strength. Recently, Walker and colleagues (2016) reported greater strength gains when training with an accentuated ECC load compared to traditional iso-inertial loading, but found no differences between the groups for muscle hypertrophy. Hortobágyi and colleagues (2001) reported similar gains in CON strength, but greater isometric and ECC strength gains after training with an accentuated ECC load. Together these studies suggest potential benefits may exist when utilizing *accentuated* load ECC training.

One technique to study ECC training using iso-inertial loading involves the controlled lowering of a weight to lengthen the overall time of the ECC contraction (Schroeder et al. 2004; Gillies et al. 2006; Krentz et al. 2008; Dias et al. 2015; Krentz et al. 2017). This technique has practical advantages over *accentuated* ECC training in that it is more user friendly and easier to perform due to the fact that additional loading of the ECC component (which requires special equipment or additional personnel to increase the load mid-repetition) is not required. Our lab has utilized this technique to study isolated ECC contractions (Krentz et al. 2008; Krentz et al. 2017) but very little is known about the effects of extending the time of the ECC component (i.e. *emphasizing* the ECC phase) when coupled with conventional CON training. Gillies et al (2006) had groups train with either emphasized ECC contractions with a shorter CON portion or emphasized CON contractions with a shorter ECC portion. Total time under tension between the groups was controlled. Results of the study indicated that emphasized CON training was more effective than emphasized ECC training for increasing both type I and type II muscle fibre area immunohistochemically, but no whole muscle measures of hypertrophy were included. Concentric, ECC, and combined strength increased with training to a similar extent for both groups. More recently, a study emphasizing the ECC portion of the lift did not lead to different adaptations in either strength or functional capacity in older woman when compared to conventional training (Dias et al. 2015); however, changes in muscle size were not assessed. Various studies have also compared isolated CON training to coupled CON /ECC training and found favourable results when the ECC component was included (Colliander and Tesch, 1990; Hather et al 1991;Lacerte et al. 1992). Training with coupled CON and ECC contractions appears more effective for muscle fibre hypertrophy (Hather et al. 1991) and increasing peak torque (Colliander and Tesch, 1990; Lacerte et al., 1992) in comparison to isolated CON training.

To our knowledge, the current study is the first to measure whole muscle growth and strength using groups that have trained concentrically with varying degrees of emphasis on the ECC component of the lift. One study has examined strength increases with emphasized ECC training but did not measure muscle hypertrophy (Dias et al. 2015). Other studies have compared emphasizing either the ECC or CON component (Gillies et al. 2006) or have compared CON training groups with different loading during the ECC phase (*accentuated* ECC training) but no research has compared the strength and muscle hypertrophy adaptations using matched iso-inertial CON training (i.e. same intensity and contraction duration) incorporating varying degrees of ECC emphasis (i.e. time under tension). The purpose of this investigation was to compare groups training with conventional iso-inertial contractions (CON with a standard lowering), CON only contractions, and CON contractions with an emphasized (3 second lowering) ECC contraction. The primary hypotheses were that training with an emphasized ECC contraction would lead to greater gains in strength and muscle hypertrophy. Additionally, there is a lack of information regarding the effects of varying ECC emphasis on muscle soreness, ratings of perceived exertion, and training volume. Secondary hypotheses were that training with emphasized ECC contractions would result in greater muscle soreness as well as less total training volume due to a higher time under tension spent on each individual repetition.

4.3 Methods

4.3.1 Participants

Ethical approval for the study was obtained from the University of Saskatchewan Biomedical Ethics Review Board, and all participants gave informed written consent before participating. A total of 58 (30 male) participants were initially enrolled in the study and completed the pre-testing procedures. Young healthy males and females with varied training experience (Appendix A) were included to allow for greater generalizability, and because many studies have shown similar time course of adaptation across sexes (Cureton et al. 1988; Staron et al. 1994; Abe et al. 2000, Krentz and Farthing, 2010). Once enrolled, participants were asked to continue their regular exercise regime and, if assigned to one of the training groups, to refrain from any additional targeted training of the elbow flexors aside from that prescribed in the study. Participant characteristics are outlined in Table 4.1.

4.3.2 Study Design

The study utilized a between subjects design consisting of pre and post testing after 8 weeks of unilateral elbow flexors concentration curl resistance training. Upon completion of the pre-testing session participants were randomized to one of four groups (CON80 performed CON only contractions at 80% of CON 1–repetition maximum (1RM), CON/ECC80 performed a CON contraction followed by a 3 second long emphasized ECC contraction at 80% of CON 1RM, Conventional80 performed conventional CON contractions with a conventional, self-paced ECC contraction at 80% of CON 1RM or a control group that did no training) in a

Table 4.1 Participant Characteristics

	CON80 (n=10 3F)	CON/ECC80 (n=13 6F)	Conventional80 (n=14 7F)	Control (n=15 8F)
Age (y)	21.5 ± 2.9	23.3 ± 6.4	22.2 ± 5.9	21.7 ± 3.2
Height (cm)	171.3 ± 5.0	172.5 ± 10.5	170.6 ± 9.3	170.4 ± 10.0
Weight (kg)	82.1 ± 15.4	73.4 ± 12.4	69.1 ± 8.3	68.6 ± 11.6
Training Experience (m)	33.9 ± 20.8	46.6 ± 58.9	32.6 ± 44.5	17.6± 15.8

All data in table is mean ± standard deviation.

counterbalanced fashion using a random number generator (www.random.org), with stratification by sex. All measurements were taken in the same order for each participant on pre- and post-intervention visits. Specifically, participants' dominant arm muscle thickness was measured first followed by CON iso-inertial 1RM of that same arm.

During the eight weeks of training, CON concentration curl 1RM was reassessed at the start of weeks 3 and 6. Monitoring of 1RM during the study allowed for adequate prescription of 80% training intensity according to each participant's individual progression in CON 1RM strength.

4.3.3 Training programs

All training groups performed dominant limb unilateral training of the elbow flexors (i.e. concentration curls). CON80 and CON/ECC80 performed training until volitional fatigue while Conventional80 was prescribed 8-12 reps per set which is inline with the American College of Sports Medicine position stand recommendations for strength and muscle hypertrophy (Ratamess et al. 2009). All groups used iso-inertial loading (i.e., dumbbell hand-held weights). Volitional fatigue was defined as the point where the participant could no longer complete the lift through the full range of motion. The non-dominant limb was used to assist the dominant limb of the CON80 group in lowering the weight so as to eliminate the performance of the ECC contraction for the dominant limb as much as possible. The training period of the study lasted 8 weeks and involved progressive overload. Participants started their first training session by completing 3 sets of their assigned contractions to volitional fatigue. The training progression then continued by adding one set to each training session until participants reached 6 sets. Rest between sets was two minutes. Past research from our lab has shown that intense training eccentrically every second day for 20 days using a dynamometer resulted in reduced strength and general overtraining (Krentz and Farthing, 2010). For this reason, participants trained 2 sessions a week with at least 72 hours rest in between sessions for the first 2 weeks and then progressed to 3 training sessions a week for the final 6 weeks of the study. If a participant was able to perform more than 20 repetitions for all prescribed sets, they were instructed to increase the training weight for the next training session. However, this increase was only prescribed if the increased training load still remained within 10% of the prescribed training intensity of 80% 1RM. Additionally, if participants were not able to perform at least 4 repetitions for all prescribed sets, the training weight was lowered for the next training session. As above, this decrease was only permitted if the load remained within 10% of the assigned training intensity. These practical modifications allowed for training to be performed until volitional fatigue for the appropriate groups (CON80 & CON/ECC80) during all sessions while ensuring that training was performed within the prescribed repetition ranges (i.e. 8-12) appropriate for maximally increasing both strength and hypertrophy (Ratamess et al. 2009). At the completion of the training phase, participants were given a minimum of 72 hours rest before completing the post testing session to ensure full recovery.

4.3.4 Measures

4.3.4.1 Muscle Thickness

Muscle thickness of the dominant elbow flexors was measured before and after the 8 weeks training period using B-mode ultrasound (LOGIQ e BTO8, GE Healthcare, Milwaukee, Wisconsin, USA) according to our previous methods (Farthing et al. 2005; Krentz and Farthing, 2010). The coefficient of variation for this technique for elbow flexors is 2.14% (Krentz and Farthing, 2010).

Muscle thickness measures always preceded strength measures to avoid the confounding effects associated with transient muscle edema. Elbow flexor muscle thickness was taken on the midline of the biceps brachii muscle belly between the medial acromion and the fossa cubit, approximately 1/3 of the distance away from the fossa cubit. Once this point was established a detailed land marking procedure (using overhead transparencies) was employed to ensure exact placement of the ultrasound probe pre and post training (Farthing and Chilibeck, 2003a; Krentz and Farthing, 2010). Four measurements were taken and the average of the two closest measurements was used to calculate the muscle thickness value.

4.3.4.2 Iso-inertial Maximal Strength Testing

Iso-inertial strength of the elbow flexors of the dominant arm was assessed using a maximal unilateral CON concentration curl. Briefly, a concentration curl is a movement where, in a seated position, one arm is rested against the upper thigh for support and the elbow flexors are used to lift a dumbbell (Figure 4.1). Participants were instructed to lift the weight off the ground vertically and then pause briefly before attempting the actual lift. Instructions were given to lift the weight in a controlled fashion without leaning their upper body back or other postural compensations.

Prior to beginning maximal lifts, participants were given a light weight to perform 1-2 warm-up sets. Participants then attempted a weight they were confident they could lift. Participants then rested before performing the next weight (approximately 2-3 minutes). One

Figure 4.1 Concentration Curl Set-up

repetition maximum was determined as the highest weight that could be successfully lifted one time. The coefficient of variation for repeated measurements of elbow flexor muscle strength in our laboratory is less than 1% (Krentz et al. 2008).

4.3.4.3 Muscle Soreness

Muscle soreness of the dominant arm was tracked daily the first 3 weeks of the study using a visual analog scale (VAS) (Appendix D), where participants indicated their degree of muscle soreness from 0 to 100 by making a mark on a 100mm horizontal line on paper. Muscle soreness was monitored only for the first 3 weeks of the study, since our previous research suggests soreness peaks within the first few weeks of training and then decreases to near zero (Krentz et al. 2008). Soreness scores were recorded after completing a standard movement, involving first lengthening and then shortening (contracting) the biceps in a slow controlled manner. When reporting soreness on a training day, participants were instructed to always record soreness prior to the training session.

4.3.4.4 Ratings of Perceived Exertion

All participants were instructed to record a session RPE score in their training log (Appendix C) upon completion of training each day, using a modified session RPE scale (Foster et al. 2001; McGuigan and Foster, 2004) (Appendix E). The scale ranges from 1 to 10, with accompanying verbal descriptions of each numerical rating. Participants were instructed to wait 30 minutes after the training session and then used this scale to indicate a composite RPE for the training session based on the question “How was your workout?” (McGuigan and Foster, 2004). This RPE scale has been reported as a valid measure of both aerobic and anaerobic exercise

(Foster et al. 2001). Specific to resistance training, session RPE is a valid (Sweet et al. 2004) and reliable (Day et al. 2004; McGuigan et al. 2004) monitoring tool.

4.3.4.5 Volume Load

All participants were instructed to record the number of repetitions completed and load utilized during each set of training (Appendix C). From this data, average volume load per training session was calculated. Volume load was calculated by multiplying the total number of repetitions completed by the training load (kg) for each training session (McBride et al. 2009). All completed training sessions were tallied and then the total volume load was divided by the total number of possible training sessions for each participant (22 total sessions) to calculate an average volume load per training session.

4.3.5 Data Analysis

Data distributions were tested for statistical assumptions of normality before proceeding with further omnibus tests. All data analyses were performed with IBM SPSS, version 22 for Windows. Percent change scores for muscle thickness and CON 1-RM were calculated as (post score – pre score) / pre score x 100. Using the percent change score, post-training muscle thickness and CON 1RM iso-inertial strength were assessed via one-way MANOVA (group [CON80, CON/ECC80, Conventional80, Control]). MANOVA was followed by univariate ANOVA when appropriate for each of the variables. Muscle soreness and RPE were analyzed separately using 2 way (group [CON80, CON/ECC80, Conventional80] × time [cumulative weekly score for week 1, week 2, week 3 for muscle soreness; average daily score for weeks

1+2, weeks 3+4, weeks 5+6, weeks 7+8 for RPE]) ANOVA with repeated measures on the last factor. Simple effects analysis and post hoc multiple comparisons (adjusted for familywise error) were performed when appropriate. Volume load was analyzed using a univariate ANOVA to examine potential differences between the three training groups (CON80, CON/ECC80, Conventional80). Effect size was calculated for MANOVA and ANOVA. Effect size values are generally accepted as follows: 0.1 = small, 0.3 = medium, 0.5 = large (Cohen, 1992). Significance was set at p<0.05.

4.4 Results

4.4.1 Participants

Of the 58 participants initially enrolled, 52 completed the study (Table 4.1). Details of those who withdrew were as follows: CON80 one male, three females; CON/ECC80 one female; Conventional80 one male. Reasons for withdrawal were participant's personal choice.

4.4.2 Muscle Thickness and Strength

MANOVA revealed a significant group effect (Pillai's Trace = 0.654, F (6,96) = 7.783, p<0.001). Univariate ANOVA revealed a significant group effect for muscle thickness (F (3,48) = 2.85, p<0.05 partial η^2 = .151). Pairwise comparisons on post-training means, revealed that CON/ECC80 (4.4%) was significantly greater than both CON80 (-0.3%) (p<0.05) and Control (-0.7%) (p<0.05) but not Conventional80 (2.0%) (p>0.05). There were no significant differences between any other groups (Figure 4.2).

Univariate ANOVA for strength revealed a significant group effect (F (3,48) = 17.354, p<0.001 partial η^2 = .520). Pairwise comparisons on post-training means, revealed that all training groups

CON80 (16.0%) ($p<0.001$), CON/ECC80 (14.3%) ($p<0.001$) and Conventional 80 (19.3%) ($p<0.001$) were significantly different than Control (-0.7%). There were no significant differences between any of the three training groups (Figure 4.3).

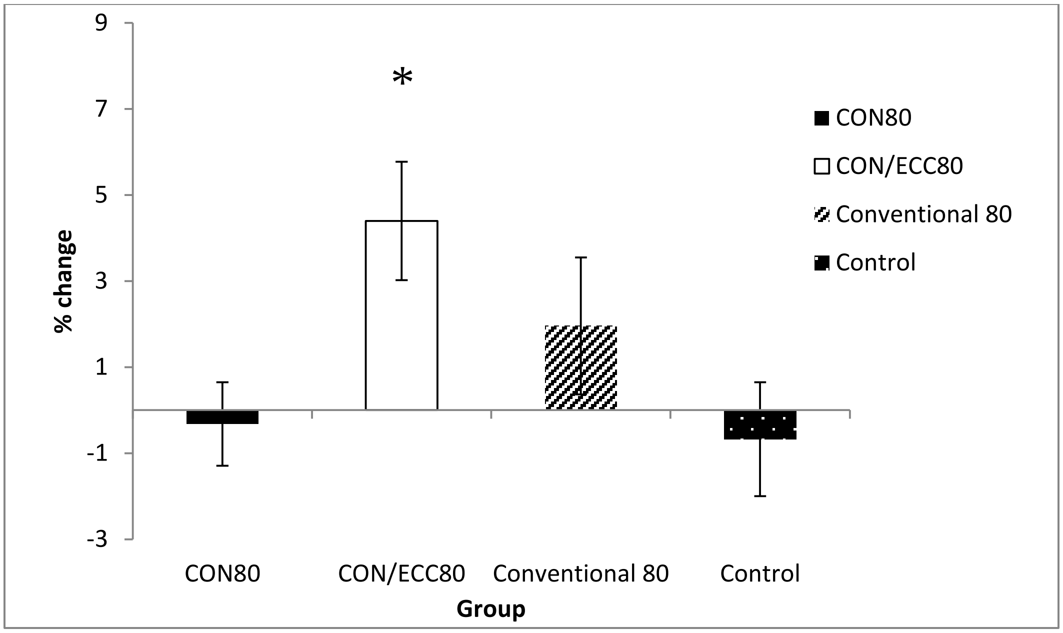


Figure 4.2 Muscle thickness percent change. * Indicates CON/ECC80 significantly different than both CON80 (p<0.05) and Control (p<0.05).Values are means ± SEM

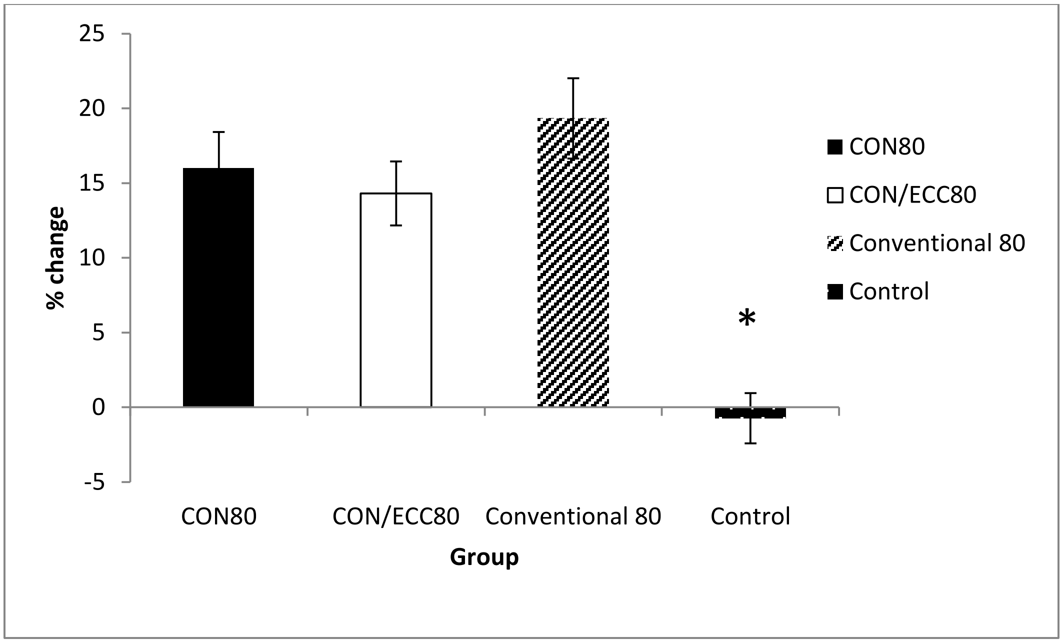


Figure 4.3 Strength percent change. * All training groups significantly different from control (p<0.001). Values are means ± SEM

4.4.3 Volume Load

Results of the univariate ANOVA indicated the effect of group was not significant, (F (2, 32) = 1.007, p>0.05 partial η^2 =.059) (Figure 4.4), therefore, volume load of training was not different between training groups. When average reps per training session were calculated there were also no significant differences between groups (p>0.05). Average repetitions performed per group were as follows: CON80 47.0, CON/ECC80 39.7, Conventional80 48.2.

4.4.4 Muscle Soreness

Results of the omnibus ANOVA revealed a significant main effect of time, Huynh-Feldt (HF), (F (1.927,52.03) = 3.294, p<0.05 partial η^2 = .109). There was no significant main effect of group (p=0.498) and no group × time interaction (p=0.414) (Figure 4.5). Soreness decreased similarly for all groups as training progressed.

4.4.5 Ratings of Perceived Exertion (RPE)

There was no significant main effect of time (HF (F 3,84) = 1.238, p=.301 partial η^2 = .042) or group (p=.191) and no group × time interaction (p=.442) (Figure 4.6). RPE were consistent both within and between groups for the duration of the study.

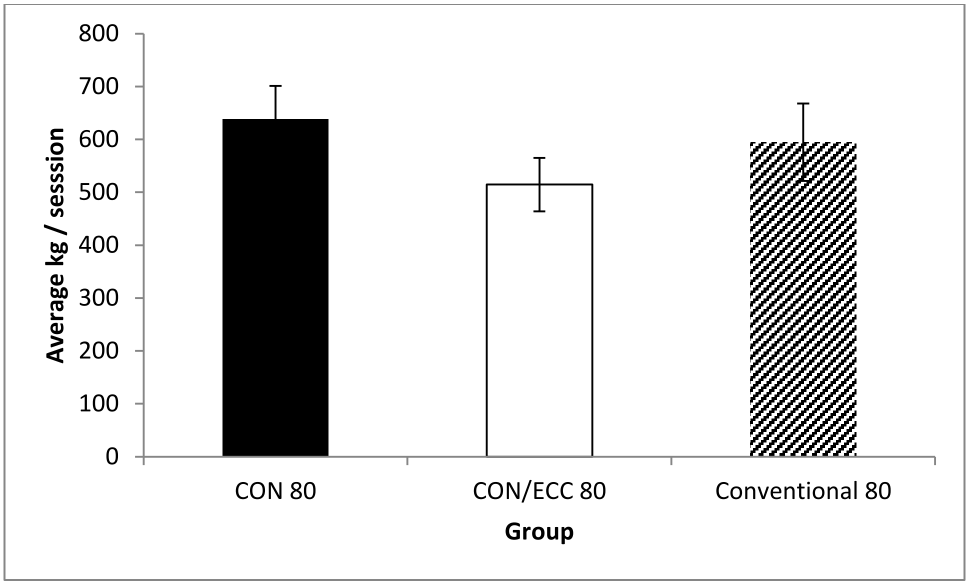


Figure 4.4 Average volume load per training session for each training group. Values are means ± SEM

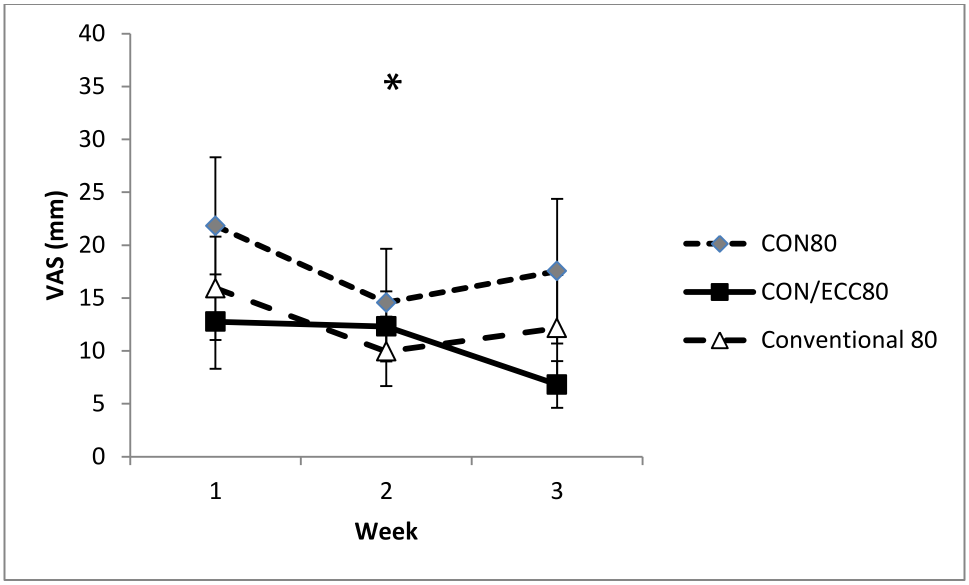


Figure 4.5 Cumulative Weekly Muscle Soreness using a Visual Analog Scale (VAS). *

Indicates significant main effect of time pooled across groups (*p*<0.05).Values are means ± SEM

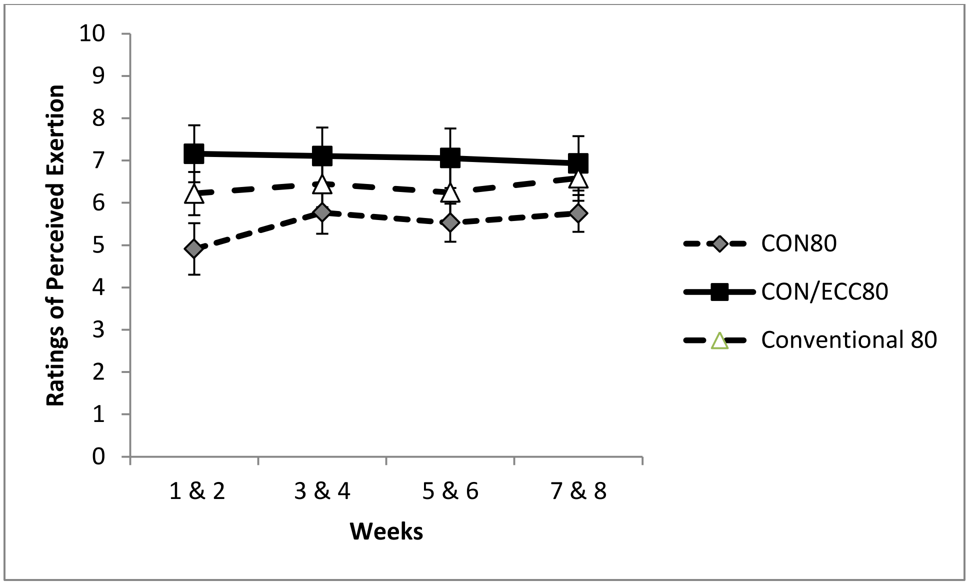


Figure 4.6 Biweekly Ratings of Perceived Exertion. Values are means ± SEM

4.5 Discussion

The main finding of the current study is that iso-inertial CON training with an emphasized ECC component (CON/ECC80) was the only training intervention to show a significant increase in muscle hypertrophy compared to the control group (Figure 4.2) but that all three training groups resulted in similar increases in CON strength (Figure 4.3). The potential importance of the ECC component of iso-inertial training was additionally highlighted when examining the absence of increased muscle size (-0.3%) (Figure 4.2) present when training only with CON contractions (CON80). Several studies have examined training outcomes utilizing iso-inertial ECC contractions emphasized over longer lowering times (Gillies et al. 2006; Krentz et al. 2008; Dias et al. 2015; Krentz et al. 2017) but the present study is the first to compare both muscle hypertrophy and strength outcomes between groups training with iso-inertial load CON training coupled with varying degrees of ECC emphasis. These findings suggest that emphasizing the ECC component of coupled iso-inertial conventional training may be optimal for muscle hypertrophy and can be performed without exacerbating symptoms of muscle soreness or increasing RPE and compromising increases in CON strength. The current findings are noteworthy given that *emphasized* ECC training is user friendly and easier to perform than other ECC techniques that require additional personnel or equipment such as *accentuated* ECC training or isokinetic dynamometry.

The finding of greater muscle hypertrophy with emphasized ECC training is novel when compared to past studies utilizing variations of emphasized ECC training protocols (Gillies et al. 2006; Dias et al. 2015). Gillies et al. (2006) reported greater type I and II fibre area hypertrophy after time matched CON comparted to emphasized ECC training but did not take any measures of whole muscle hypertrophy. Dias et al. (2015) compared conventional to emphasized ECC training but did not attempt any muscle hypertrophy measures. The findings of the current study are congruent with other studies highlighting greater muscle hypertrophy through the inclusion (Hather et al. 1991) or optimization (English et al. 2014) of the ECC component of conventional lifts. As well, the current study results support recent findings of superior muscle growth with ECC flywheel overload resistance training (Maroto-Izquierdo et al. 2017) and isolated ECC training (Coratella and Schena, 2016) when compared to traditional resistance training protocols.

Enhanced muscle hypertrophy in the group that trained with emphasized ECC contractions (CON/ECC80) (Figure 4.2) is not surprising when considering time under tension and further examining the training volume data in the current investigation (Figure 4.4). Training to failure with emphasized ECC contractions was expected to result in the performance of fewer total repetitions and accordingly a lower overall training volume due to the longer time under tension spent during each repetition. This hypothesis was not supported as results indicated no significant differences between any of the training groups for average training volume per session (Figure 4.4). When considering equal training volume between groups, CON/ECC80, which utilized a three-second ECC lowering protocol, had a longer total time under tension than the other two training groups. This is undoubtedly partially responsible for the enhanced hypertrophy response in the CON/ECC80 group as time under tension is an established predictor of muscle hypertrophy (Vandenburgh, 1987; Goldspink, 2002). More surprising is that performance of the longer eccentrically emphasized repetitions (coupled with conventional CON) seemingly did not induce volitional fatigue any faster than training with CON only or conventional contractions and therefore led to equal training volumes (Figure 4.4). Pasquet and colleagues (2000) suggest that calcium controlled excitation contraction compelling processes are affected more during CON than ECC contractions. Interestingly, our data may also indirectly support the idea that fatiguing parameters may be different between ECC and CON contractions.

Past research indicates mixed findings regarding variations of ECC contractions and their ability to increase CON strength (Higbie et al. 1996; Hortobágyi et al. 1996; Seger et al. 1998; Farthing and Chilibeck, 2003b; Roig et al. 2009; Krentz et al 2017). The current results indicate that all three training groups significantly increased strength compared to control with no differences between any of the groups (Figure 4.3). This suggests that when performing CON training with iso-inertial loading, the degree of ECC emphasis has little effect on iso-inertial CON strength outcomes. This finding directly supports the findings of Dias and colleagues (2015) who also reported no differences in strength or functional outcomes in older women who performed either conventional or eccentrically focused resistance training. Interestingly, the current study and that of Dias et al. (2015) utilized similar training methodology (3s vs 4.5s ECC emphasis, 8 weeks vs 12 weeks total study length, 2-3/week vs 2/week training frequency) and subsequently reported very similar strength findings, even though the study populations were very different (untrained older women vs. young healthy men and women with varied training history). Two major differences between the current study and that of Dias et al. (2015) were that the current study utilized heavier relative loading (80% of 1RM for all groups) and had all groups train until failure whereas Dias et al. (2015) utilized lighter loads (45%-75% 1RM) and had participants perform a set number of repetitions (12 for each group). Isolated ECC training is inferior in its ability to increase CON strength as comparted to CON training (Higbie et al. 1996; Hortobágyi et al. 1996; Seger et al. 1998; Roig et al. 2009), suggesting that if CON strength is an important outcome, combined or coupled CON/ECC training may be a better approach to concurrently optimize strength and muscle growth. Another method of optimizing the ECC component of a lift during conventional training has been to accentuate the ECC load (Hather et al. 1991; English et al. 2014; Walker et al. 2016). Whereas the current study reports enhancement of muscle hypertrophy after emphasized ECC training (Figure 4.2) similar to that of previous studies prescribing accentuated load ECC contractions (Hather et al. 1991; English et al. 2014), results for strength are more unresolved. Two studies utilizing accentuated load ECC conventional training have found enhanced strength outcomes compared to conventional training (English et al. 2014; Walker et al. 2016) whereas Hortobágyi and colleagues (2001) reported similar gains in CON strength between conventional and accentuated ECC loading. One major difference between the previously mentioned accentuated ECC loading studies (Hortobágyi et al. 2001; English et al. 2014; Walker et al. 2016) was that Hortobágyi and colleagues (2001) attempted to control the total training volume lifted between groups by reducing the number of repetitions performed in the ECC emphasized group whereas both English et al. (2014) and Walker et al. (2016) kept repetitions and sets the same across groups, allowing total training time under tension to vary. Taken as a whole, the current data suggests conventional CON training coupled with accentuated ECC training may be slightly more effective for optimization of CON strength outcomes compared to emphasizing the ECC component over a longer time as was done in the current investigation and by Dias et al. (2015). This conclusion supports past studies (Rana et al. 2008; Mitchell et al. 2012; Schoenfeld et al. 2015) and recommended training prescriptions (Ratamess et al. 2009) suggesting that exposure to higher intensities (ie. greater loading during the accentuated ECC phase) is most effective for increasing maximal strength.

The current findings for muscle soreness are surprising. It is well established that ECC training results in delayed onset muscle soreness (Nosaka and Clarkson, 1996; Tokmakidis et al. 2003; Krentz and Farthing, 2010) and thus we hypothesized that CON/ECC80 would have significantly greater muscle soreness compared to the other training groups. Our results indicate no differences between any of the training groups for this measure (Figure 4.5). This is especially perplexing when considering the potentially higher time under tension that CON/ECC80 was exposed to as a result of the emphasized ECC component. Most commonly, studies reporting on ECC related muscle damage and soreness have used some form of isolated ECC contractions, often with maximal intensities (Nosaka and Clarkson, 1996; Tokmakidis et al. 2003; Krentz and Farthing, 2010). The current study utilized a relative intensity of 80% of CON 1RM for all training groups, a relatively low submaximal intensity relative to one's ECC maximal strength. Nosaka and Newton (2002) reported lower markers of muscle damage after submaximal ECC training, which may partially explain why there were findings of similar muscle soreness between groups with or without submaximal ECC emphasis. Still, Dias and colleagues (2015) utilized a similar training protocol to the current study, commenting that those training with eccentrically focused contractions reported more muscle pain and discomfort with training, although their study differed from the current study in that their study was performed on untrained older adults and the current study involved young adults of varied training backgrounds. LaStayo and colleagues (2007) suggest that ECC training can be performed safely and with minimal damage and the current investigation is congruent with the idea that well-designed and progressive training programs can be well tolerated regardless of the degree of ECC emphasis included. This is supported by the fact that muscle soreness went down collectively across all groups as training progressed (Figure 5).

Eccentric contractions result in lower ratings of perceived exertion (Hollander et al. 2003) and lower oxygen cost per unit of force (LaStayo et al. 1999; Meyer et al. 2003) than CON contractions. Less is known about ratings of perceived exertion with coupled CON and emphasized or accentuated ECC training. One study (Diniz et al. 2014) compared four second (two seconds CON, two seconds ECC) and six second contractions (two seconds CON, 4 seconds ECC) to self-paced duration contractions and found higher RPEs for six but not four second contractions comparted to those that were self-paced. Interestingly, in their study an ECC contraction of doubled time (4s vs 2s) lead to higher reported RPE (Diniz et al. 2014); but in the current study, having no ECC, a self-paced ECC, or a three second ECC contraction all produced similar ratings of perceived exertion when coupled with conventional iso-inertial CON contractions (Figure 4.6). One potential reason for the disparity between the results of Diniz et al. (2014) and the current study is the repetition prescription protocol in each study. Diniz et al. (2014) prescribed 6 repetitions per set for each condition whereas the current study had all groups train until volitional fatigue. Therefore, having each group train to failure, regardless of group, may have resulted in similar RPE reporting between groups in the current study.

In conclusion, the current study is the first to investigate both muscle hypertrophy and strength outcomes after iso-inertial CON training with varying degrees of ECC emphasis. The main finding of increased muscle hypertrophy after conventional iso-inertial with emphasized ECC training compared to control along with equal strength gains has noteworthy practical training implications. The results highlight the importance of concentrating on the ECC portion of the lift during conventional iso-inertial training in order to optimize both CON strength and muscle hypertrophy. Often training prescriptions are based on CON strength values (Ratamess et al. 2009) and the ECC portion of the lift may be under-stressed or even neglected. This study adds to a growing body of literature suggesting that optimization of training outcomes requires specific attention be paid to the ECC portion of the lift either by increasing the time under tension (i.e. emphasizing) in the ECC phase (Dias et al. 2015) or by accentuating the load during the ECC portion (Hather et al. 1991; English et al. 2014; Walker et al. 2016) in order to better access the force producing potential of the ECC component of a lift. Although CON/ECC was shown to better than CON80 or control for muscle hypertrophy, it should not be overlooked that in the current study emphasizing the ECC phase of the lift did not result in greater strength or muscle hypertrophy when compared directly to conventional training.

The current study was limited by the fact that only one relatively small muscle group (elbow flexors) was trained and thus extrapolation of these findings to whole body and large more complex movements may be limited. Future studies should seek to investigate this type of training with more complex, functionally relevant movements (i.e. squat or bench press). Along with extending the results of the current study to more relevant exercises, future research should continue to study the most optimal, accessible and practical methods to incorporate and optimize eccentrically focused training. The current study utilized longer duration ECC contractions to emphasize the ECC portion during conventional iso-inertial training whereas other recent studies have used isolated iso-inertial ECC contractions (Krentz et al. 2017) or accentuated ECC training coupled with conventional CON training (Walker et al. 2016). To our knowledge no studies to date have compared iso-inertial emphasized ECC vs. accentuated load ECC protocols when both incorporate conventional CON training in order to make direct comparisons of which may be more effective training strategies.

Conflicts of Interest: The authors declare that they have no conflict of interest

Thesis Transition and Author Contribution – Study 3

Study two's practical findings regarding emphasized eccentric training compliment the more theoretical findings from study one. Together, both study one and two highlight the effectiveness of two forms of iso-inertial training, isolated and CON/ECC emphasized. Building from these studies, study three utilized a factorial analysis to investigate the interplay between contraction type and intensity of training. Specifically, the addition of isokinetic strength measures along with the iso-inertial measures allowed for a more complex analysis of the role of specificity in strength adaptation across contraction types and between training devices.

It should be noted that three of the four groups in study three have been previously reported on in studies one and two. Both of the first two studies utilized analysis that compared to a non-training control group and did not make direct comparisons between isolated contraction types. Study three used a repeated measures factorial design which allowed for group main effects and interaction analysis to be performed, providing a deeper level of understanding into the interplay between intensity and contraction type related adaptations to training. Study three also includes a larger battery of physiological measures not included for any of the groups in study one or two.

Contribution:

Joel Krentz was the lead contributor to this study and was involved in all aspects of the study including study design, participant recruitment, data acquisition, data analysis, and manuscript preparation. This manuscript has not yet been submitted for publication but when it is Joel Krentz will be the first author.

Chapter 5 – Study Three

The effects of high and low intensity eccentric and concentric iso-inertial training on strength, isokinetic peak torque and muscle hypertrophy

5.1 Abstract

Both contraction type and training intensity are important variables to consider during resistance training. To date, no study has compared isolated high and low intensity eccentric (ECC) and concentric (CON) training when utilizing an iso-inertial (i.e. free weight) protocol. PURPOSE: To compare groups utilizing either high or low intensity iso-inertial resistance training with either CON or ECC contractions until volitional fatigue on strength, muscle activation, evoked contractions, and muscle hypertrophy. METHODS: Thirty-eight (25 male) participants were randomized into one of 4 groups: 1) CON HIGH performed CON only contractions at 80% of CON 1–repetition maximum (1RM); 2) ECC HIGH performed ECC contractions at 110% of CON 1RM; 3) CON LOW performed CON contractions at 30% of CON 1RM; and 4) ECC LOW performed ECC contractions at 80% of 1RM. Training progressed from 3 to 6 sets of unilateral elbow flexors over 8 weeks. CON iso-inertial 1RM, isokinetic CON, ECC, and isometric (ISO) peak torque (via dynamometer), elbow flexors muscle thickness (via ultrasound), muscle activation (via electromyography), and resting twitch torque (via electrically evoked contractions) were measured pre- and post-training. Rating of perceived exertion (RPE) and muscle soreness were self-reported. Repeated measures factorial MANOVA and ANOVA were used to compare training groups over time. RESULTS: For CON iso-inertial 1RM, a three way intensity x contraction type x time interaction revealed CON HIGH resulted in a significantly greater increase pre- to post-training compared to CON LOW ($p<0.05$) while a time main effect was present for ECC training, grouped across intensity ($p<0.05$). Analysis revealed an intensity × time interaction ($p<0.05$) in which HIGH training groups were superior to LOW for increasing both isokinetic ECC (+6.6 Nm vs -0.3Nm, $p<0.05$) and CON (+4.7 Nm vs -0.5 Nm, $p<0.05$) peak torque. There were no significant contraction type × time interactions for isokinetic peak torque ($p>0.05$). A contraction type × time interaction ($p<0.05$) revealed change in muscle thickness was greater in groups that trained using ECC (+0.23cm) compared to CON (+0.03cm) contractions. There were no intensity × time interactions for muscle thickness ($p>0.05$) and were also no significant group or time effects for resting twitch torque or muscle activation ($p>0.05$). CONCLUSION: When training with iso-inertial protocols, high intensity contractions lead to greater isokinetic strength gains while isolated ECC training leads to greater muscle hypertrophy.

5.2 Introduction

Contraction type and training intensity are key variables that must be considered when designing resistance training programs (Ratamess et al. 2009). Variations in each are often manipulated depending on a number of situation and outcome specific factors such as the desired goal (i.e. strength, muscle hypertrophy), the modalities available for training (i.e. iso-inertial, isokinetic) or the training population (i.e. athletes, older adults). Individually, each variable has been studied in great detail. Specifically, original investigations (Hisaeda et al. 1996; Chestnut et al. 1999; Tanimoto et al. 2006; Mitchell et al. 2012; Alegre et al. 2015; Krentz et al. 2017) and topical reviews (Fisher et al. 2013; Schoenfled et al. 2016; Fisher et al. 2017) have compared adaptations resulting from high versus low intensity training. Similarly, the effectiveness of ECC versus CON training has been extensively examined (Higbie et al. 1996; Seger et al. 1998; Hortobágyi et al. 1996; Farthing and Chilibeck, 2003b; Roig et al. 2009). Interestingly, little is known about the interaction of training intensity and contraction type when studied together, especially when training is performed using conventionally utilized iso-inertial loading (i.e. dumbbells). To date, no study has compared isolated high and low intensity ECC and CON iso-inertial training.

Greater force is produced during ECC compared to CON contractions (Sale et al. 1987; Hortobáygi and Katch, 1990; Westing et al. 1990; Westing et al. 1991; Farthing and Chilibeck, 2003b). It is generally accepted that isolated ECC training leads to greater muscle hypertrophy than isolated CON training (Higbie et al. 1996; Seger et al. 1998; Hortobágyi et al. 1996; Farthing and Chilibeck, 2003b; Roig et al. 2009) although when relative load is controlled for similar changes in muscle mass between ECC and CON training may occur (Franchi et al., 2014, 2015). Eccentric training is also more effective for increasing total overall strength (Farthing and Chilibeck, 2003b; Roig et al. 2009). A systematic review by Roig and colleagues (2009) examined the issue of ECC versus CON training and concluded that ECC training, when performed at a higher intensity than CON training, was more effective for increasing total strength and muscle mass. In accordance with the principle of specificity, isolated ECC training is inferior for increasing CON strength as comparted to CON training (Higbie et al. 1996; Hortobágyi et al. 1996; Seger et al. 1998; Roig et al. 2009). As well, acute sessions of ECC training in unaccustomed individuals are associated with delayed onset muscle soreness and decreased strength (Nosaka and Clarkson, 1996; Tokmakidis et al. 2003; Krentz and Farthing, 2010).

Traditionally, high training loads (80-100% 1RM) are preferred for increasing strength and moderate to high loads (70-100% 1RM) are recommended for muscle hypertrophy (Ratamess et al. 2009). Investigations comparing both concentrically-focused (Hisaeda et al. 1996; Chestnut et al. 1999; Tanimoto et al. 2006; Mitchell et al. 2012; Alegre et al. 2015) or isolated ECC training (Krentz et al. 2017; see study 1) suggest that training-induced muscle hypertrophy may be similar with high and low intensity training. Research suggests that higher intensities are more effective than lower intensities for increasing strength (Rana et al. 2008; Mitchell et al. 2012; Schoenfeld et al. 2015) although this is not the case when training eccentrically and then testing concentrically with iso-interial loads (Krentz et al. 2017). Most studies comparing high and low intensities test and train participants using the same equipment in accordance with the theory of specificity. Less is known about the transferability of strength gains from iso-inertial training to laboratory based strength testing such as isokinetic dynamometry.

When strength is tested on similar movements across isokinetic and iso-inertial modalities, a strong relationship between the tested strength values exists. (Jacobs et al. 1988; Hortobágyi et al. 1989; Murphy and Wilson, 1996). Conversely, this relationship is not present when training is performed on one modality and then tested on a unique modality. Several studies have shown that when training is performed with iso-inertial loads (e.g. dumbbells or machines) iso-inertial 1RM strength increases are significantly greater than isokinetic strength increases (Feiereisen et al. 20101; Lima et al. 2012; Gentil et al. 2017). Recently, Stock and colleagues (2017) had subjects train with iso-inertial CON loads and then tested CON isokinetic strength. Results of this study indicated that iso-inertial training was not effective for increasing isokinetic strength. To date, very little is known about the transferability between modalities when training is performed with different intensities (high vs. low) or contraction types (ECC vs. CON).

To our knowledge, no research has compared iso-inertial and isokinetic strength adaptations after high and low intensity iso-inertial training. Additionally, no study has investigated how the contraction type used in training affects both modality (i.e. iso-inertial and isokinetic) and contraction type specific strength gains. The purpose of this investigation was to explore the interplay of contraction type and intensity on iso-inertial and isokinetic strength and muscle hypertrophy adaptations by comparing training with high and low intensity ECC or CON iso-inertial contractions. The primary hypothesis was that high intensity CON iso-inertial training would lead to the greatest gains in iso-inertial CON 1RM due to mode, intensity and contraction type specificity. Additionally, it was hypothesized that training with high intensities would lead to greater total strength increases across modalities, and that training with a given contraction type would lead to greater gains in isokinetic strength specific to training (i.e., CON training would best increase CON isokinetic strength and ECC training would be best for ECC isokinetic strength).

5.3 Methods

5.3.1. Participants

Ethical approval for the study was obtained from the University of Saskatchewan Biomedical Ethics Review Board, and all participants gave informed written consent before participating. A total of 58 (31 male) participants were initially enrolled in the study and completed the pre-testing procedures. Young healthy males and females with varied training experience (Appendix A) were included to allow for greater generalizability, and because many studies have shown similar time course of adaptation across sexes (Cureton et al. 1988; Staron et al. 1994; Abe et al. 2000, Krentz and Farthing, 2010). Once enrolled, participants were asked to continue their regular exercise regime and, if assigned to one of the training groups, to refrain from any additional targeted training of the elbow flexors aside from that prescribed in the study. Participant characteristics are outlined in Table 5.1.

It should be noted that we have previously published data that included analyses comparing the same ECC training groups as are included in the current study (Krentz et al. 2017). That study used a covariate analysis comparing to a non-training control group and did not make any comparisons to CON training groups. The current study used a repeated measures factorial design which allowed for group main effects and interaction analysis to be performed, providing a deeper level of understanding into the interplay between intensity and contraction type related adaptations to training. The current study also includes a larger battery of physiological measures.

5.3.2 Study Design

The study utilized a between subjects design consisting of pre and post testing after 8 weeks of unilateral elbow flexors concentration curl resistance training. Upon completion of the pre-testing session participants were randomized to one of four groups: 1) CON HIGH performed CON only contractions at 80% of CON 1–repetition maximum (1RM); 2) ECC HIGH, ECC contractions at 110% of CON 1RM; 3) CON LOW performed CON contractions at

Table 5.1 Participant characteristics

Group	ECC HIGH (n=8 5M:3F)	ECC LOW (n=9 7M:2F)	CON HIGH (n=10 7M:3F)	CON LOW (n=11 6M:5F)
Age (years)	26.3 ± 6.7	23.3 ± 7.4	21.5 ± 2.9	22.5 ± 5.2
Height (cm)	174.2 ± 9.7	175.9 ± 8.0	171.3 ± 5.0	176.4 ± 9.4
Weight (kg)	74.6 ± 12.8	74.2 ± 11.1	82.1 ± 15.4	71.1 ± 15.4
Training Experience (months)	31.5 ± 20.1	21.4 ± 26.3	33.9 ± 20.8	26.5 ± 19.8

All data in table is mean ± standard deviation

30% of CON 1RM; and 4) ECC LOW performed ECC contractions at 80% of 1RM. Groups were randomized in a counterbalanced fashion using a random number generator (www.random.org), with stratification by sex. All measurements were taken in the same order for each participant on pre- and post-intervention visits. Specifically, participants' dominant arm muscle thickness was measured first followed by CON dumbbell 1RM of that same arm. During the eight weeks of training, CON concentration curl 1RM was reassessed at the start of weeks 3 and 6. Monitoring of 1RM during the study allowed for adequate prescription of training intensity according to each participant's individual progression in CON 1RM strength.

5.3.3 Training programs

All training groups performed dominant limb unilateral training of the elbow flexors (i.e. concentration curls) until volitional fatigue. Volitional fatigue was defined as the point where the participant could no longer complete the lift through the full range of motion for their assigned training repetition (could not complete the full CON portion during CON repetitions or could not control the weight down for 3 full seconds during ECC repetitions). The non-dominant limb was used to assist the dominant limb of each group in either raising or lowering the weight so as to eliminate the dominant limb's performance of the opposite contraction type as much as possible. The training period of the study lasted 8 weeks and involved progressive overload. Participants started their first training session by completing 3 sets of their assigned contractions to volitional fatigue. The training progression then continued by adding one set to each training session until participants reached 6 sets. Rest between sets was two minutes. Past research from our lab has shown that intense training eccentrically every second day for 20 days using a dynamometer resulted in reduced strength and general overtraining (Krentz and Farthing, 2010). For this reason, participants trained 2 sessions a week with at least 72 hours rest in between sessions for the first 2 weeks and then progressed to 3 training sessions a week for the final 6 weeks of the study. If a participant was able to perform more than 20 repetitions for all prescribed sets, they were instructed to increase the training weight for the next training session. However, this increase was only prescribed if the increased training load still remained within 10% of the prescribed training intensity for each group. Additionally, if participants were not able to perform at least 4 repetitions for all prescribed sets, the training weight was lowered for the next training session. As above, this decrease was only permitted if the load remained within 10% of the assigned training intensity. These practical modifications allowed for training to be performed until volitional fatigue during all sessions while ensuring that training was performed within the prescribed repetition ranges (i.e. 8-12) appropriate for maximally increasing both strength and hypertrophy (Ratamess et al. 2009). At the completion of the training phase, participants were given a minimum of 72 hours rest before completing the post-testing session to ensure full recovery.

5.3.4 Measures

5.3.4.1 Muscle Thickness

Muscle thickness of the dominant elbow flexors was measured before and after the 8 weeks training period using B-mode ultrasound (LOGIQ e BTO8, GE Healthcare, Milwaukee, Wisconsin, USA) according to our previous methods (Farthing et al. 2005; Krentz and Farthing, 2010). The coefficient of variation for this technique for elbow flexors is 2.14% (Krentz and Farthing, 2010). Muscle thickness measures preceded strength measures to avoid the confounding effects associated with transient muscle edema. Elbow flexor muscle thickness was taken on the midline of the biceps brachii muscle belly between the medial acromion and the fossa cubit, approximately 1/3 of the distance away from the fossa cubit. Once this point was established a detailed land marking procedure (using overhead transparencies) was employed to ensure exact placement of the ultrasound probe pre- and post-training (Farthing and Chilibeck, 2003a; Krentz and Farthing, 2010). Four measurements were taken and the average of the two closest measurements was used to calculate the muscle thickness value.

5.3.4.2 Iso-inertial Maximal Strength

Iso-inertial strength of the elbow flexors of the dominant arm was assessed using a maximal unilateral CON concentration curl. Briefly, a concentration curl is a movement where, in a seated position, one arm is rested against the upper thigh for support and the elbow flexors are used to lift a dumbbell (Figure 5.1). Participants were instructed to lift the weight off the ground vertically and then pause briefly before attempting the actual lift. Instructions were given to lift the weight in a controlled fashion without leaning their upper body back or other postural compensations.

Prior to beginning maximal lifts, participants were given a light weight to perform 1-2 warm-up sets. Participants then attempted a weight they were confident they could lift. Participants then rested before performing the next weight (approximately 2-3 minutes). One repetition maximum (1RM) was determined as the highest weight that could be successfully lifted one time. The coefficient of variation for measurement of elbow flexors strength in our lab is less than 1% (Krentz et al. 2008).

Figure 5.1 Concentration Curl Set-up

5.3.4.3 Isokinetic Peak Torque

Isokinetic ECC, CON, and isometric (ISO) elbow flexion peak torque of the dominant arm was assessed pre- and post-training using an isokinetic dynamometer (Humac Norm, CSMi, Boston, MA). To attempt to maximize transferability from the training mode, participants were oriented so that the isokinetic tests replicated the iso-inertial concentration curl as closely as possible. Isokinetic dynamometry allowed direct control of contraction type and velocity while accurately measuring torque production. For isometric contractions, the dominant arm was positioned so that the elbow angle was at 90 degrees as measured by a handheld goniometer. For both the CON and ECC contractions, contraction velocity was set at 45 degrees (0.79 radians) per second, over a range of 135 degrees (2.36 radians). Testing included 4 maximal contractions of each contraction type and the peak torque for each was used as the maximum value. With regards to testing order, isometric testing always occurred first. Concentric and ECC contraction testing order was counterbalanced to minimize testing order effects. Past research in our lab has reported a coefficient of variation of 6.1% for isokinetic elbow flexors strength testing (Krentz and Farthing, 2010).

5.3.4.4 Muscle Activation

Muscle activation was assessed pre- and post-training via electromyography (EMG) (Bagnoli-4, Delsys Inc., Boston, MA, USA). Muscle activation of the dominant arm was measured on the biceps during all isokinetic contractions (ISO, CON and ECC). The electrode was placed at the middle of the marked area where muscle ultrasound was measured as outlined above. This placement was recorded to ensure correct placement at the post-testing time point. The surface of the skin was cleaned with 70% isopropyl alcohol and shaved to minimize skin resistance. The EMG main amplifier unit included single differential electrodes with a bandwidth of 20 ± 5 Hz to 450 ± 50 Hz, a 12 dB/octave cutoff slope, and a maximum output voltage of ± 5 V. The overall amplification or gain per channel was 1K. The electrodes were 2 silver bars (10 mm x 1 mm diameter) spaced 10 mm apart with a Common Mode Rejection Ratio (CMRR) of 92 dB. Raw data (volts) were later converted to mean absolute value (MAV) values using custom routines in Matlab (Version 7.3.0, R2006b, Mathworks, Natick, MA) to examine changes in signal amplitude. Muscle activation was measured during all isokinetic testing repetitions and the EMG data from the repetition with the highest peak torque was used for comparison. A reference electrode was applied to a bony landmark (usually the knee or ankle) to serve as a common ground for the signal.

Custom software in LabVIEW (version 8.6) was used to obtain EMG data. Data acquisition occurred at a sampling rate of 1,000 Hz. An analog-to-digital converter (model PCI-6034E, National Instruments, Austin, TX) was used to convert the analog signal to a digital signal in LabVIEW. Raw EMG signals (in V) were converted to mean absolute value (MAV) using MATLAB (version 7.3.0). This method of EMG acquisition and signal analysis is similar to past methods we have used in our lab (Magnus et al. 2010). Before commencing acquisition of data, the signal was inspected for accuracy. Accuracy of location was assessed by having the participant both relax and perform a submaximal contraction during which the researcher visually inspected for a clean signal. No offline criteria were used for accuracy assessment. Peak isometric activation was used to normalize activation for the dynamic contractions. A one-second window of activation around the peak torque for each contraction was used for comparison. Specifically, both CON and ECC MAV activation values were divided by the peak MAV for isometric so that each end value was a normalized value representing the ratio of each specific dynamic contraction to that of the peak isometric. This process was done to attempt to minimize session to session fluctuations in activation amplitude in order to control for Type I error. Calculations for normalized EMG signal amplitude were completed using custom routines in Matlab.

5.3.4.5 Resting Twitch Torque

Resting twitch torque of the elbow flexors was assessed pre- and post-training using stimulated contractions evoked at rest similar to previous protocols utilized in our lab (Barss et al. 2014; Boychuk et al. 2016). Direct simulation of the biceps brachii was achieved using 2 electrodes placed on the skin medial and lateral to the bulk of the biceps using 2 square wave pulses (50µs wide) delivered at 100Hz from a constant current stimulator (Digitimer Model DS7AH, Digitimer, Hertfordshire, England). The current needed to elicit peak twitch torque ranged from 150-250 milliamps (mA) across participants. A series of resting control twitches were recorded to determine the maximum current (mA) needed to reach maximum resting twitch torque. The muscle was stimulated while the subject lied supine beside the dynamometer and lightly grasped the handle of the dynamometer to ensure the muscle was as relaxed as possible. The torque readings from the dynamometer were used to determine the maximal resting twitch torque. Self-adhesive electrodes were used with the cathode placed directly medial to the biceps brachii and the anode placed on the lateral side of the upper arm opposite to the cathode. The electrode placed directly medial to the biceps was pressed up and into the arm by the researcher as the stimulation current was delivered. Pilot testing revealed that this produced the most reliable and robust resting twitches in this particular setup.

5.3.4.6 Muscle Soreness

Muscle soreness of the dominant arm was tracked daily the first 3 weeks of the study using a visual analog scale (VAS) (Appendix D), where participants indicated their degree of muscle soreness from 0 to 100 by making a mark on a 100mm horizontal line on paper. Muscle soreness was monitored only for the first 3 weeks of the study, since our previous research suggests soreness peaks within the first few weeks of training and then decreases to near zero (Krentz et al. 2008). Soreness scores were recorded after completing a standard movement, involving first lengthening and then shortening (contracting) the biceps in a slow controlled manner. When reporting soreness on a training day, participants were instructed to always record soreness prior to the training session.

5.3.4.7 Ratings of Perceived Exertion

All participants were instructed to record a session RPE score upon completion of training each day, using a modified session RPE scale (Foster et al. 2001; McGuigan and Foster, 2004). The scale ranges from 1 to 10, with accompanying verbal descriptions of each numerical rating. Participants were instructed to wait 30 minutes after the training session and then used this scale to indicate a composite RPE for the training session based on the question “How was your workout?” (McGuigan and Foster, 2004). This RPE scale has been reported as a valid measure of both aerobic and anaerobic exercise (Foster et al. 2001). Specific to resistance training, session RPE is a valid (Sweet et al. 2004) and reliable (Day et al. 2004; McGuigan et al. 2004) monitoring tool.

5.3.5 Data Analysis

Data distributions were tested for statistical assumptions of normality before proceeding with further omnibus tests. All data analyses were performed with IBM SPSS, version 22 for Windows. Muscle thickness and iso-inertial strength were assessed via repeated measures factorial MANOVA. MANOVA was followed by univariate ANOVA for each of the dependent variables. When appropriate, main effects and interactions were further investigated. Isokinetic ECC, CON and isometric torque was analyzed using a 2 (intensity) × 2 (contraction type) × 2 (time) (intensity [HIGH vs. LOW] × contraction [CON vs. ECC] × time [pre, post]) repeated measures factorial MANOVA (3 dependent variables for peak torque). Muscle soreness and RPE were analyzed separately using 2 × 2 × 3 (muscle soreness) and 2 × 2 × 4 (RPE) (intensity [HIGH vs. LOW] × contraction [CON vs. ECC] × time [cumulative weekly score for week 1, week 2, week 3] for muscle soreness; average daily score for weeks 1+2, weeks 3+4, weeks 5+6, weeks 7+8 for RPE]) repeated measures factorial ANOVA. Muscle activation was analyzed using a repeated measures factorial MANOVA with two dependent variables (isokinetic ECC and CON normalized EMG) similar to the isokinetic peak torque analyses described above. Resting twitch torque was analyzed using a 2 (intensity) x 2 (contraction type) x 2 (time) repeated measures factorial ANOVA. Simple effects analysis and post hoc multiple comparisons (adjusted for familywise error) were performed when appropriate. Effect sizes are reported for MANOVA and ANOVA. Effect size values are generally accepted as follows: 0.1 = small, 0.3 = medium, 0.5 = large (Cohen, 1992). Significance was set at $p<0.05$.

5.4 Results

5.4.1 Participants

Of the 58 participants initially enrolled, 38 completed the study (Table 1). Details of those who withdrew were as follows: CON HIGH one male, three females; ECC HIGH two males, five females; CON LOW two males, two females; ECC LOW one male, four females. Reasons for withdrawal included time commitment and personal choice of the participant. Two participants from the ECC HIGH group did indicate soreness and pain as a reason for withdrawing.

5.4.2 Muscle Thickness and Iso-inertial Strength

Repeated measures factorial MANOVA for muscle thickness and iso-inertial strength revealed a significant contraction type × intensity × time interaction (Pillai's Trace = 0.280, F (2, 33) = 6.480, p<0.01 partial η^2 = .280). Univariate ANOVA revealed a significant contraction type × time interaction for muscle thickness, Greenhouse-Geisser (GG), [F (1, 34) = 11.666, p<0.01 partial η^2 = .255]. From there we investigated this interaction by splitting the data file by contraction type to further analyze how each contraction type changed over time. This breakdown analysis revealed a significant effect of time for ECC (p<0.01) but not CON (p=.378) (Figure 5.2). Overall, these results reveal that when grouped across both HIGH and LOW intensities, ECC training significantly increased muscle thickness over time but CON training did not. Univariate ANOVA for iso-inertial strength revealed a significant contraction type × intensity × time interaction, (GG), [F (1, 34) = 10.110, p<0.01 partial η^2 = .229). From there we investigated this interaction by splitting the data file by contraction type to further analyze how each contraction type changed over time. This analysis revealed a significant intensity × time interaction for CON (p<.0.01) and a significant effect of time for ECC (p<0.01) (Figure 5.3). These results reveal that for CON training, the HIGH group (14.9%) increased significantly more than the LOW group (6.2%) post training, while there was no difference between intensity for ECC groups. However, both high and low ECC training increased strength over time by 4.3% (HIGH) and 8.1% (LOW) respectively.

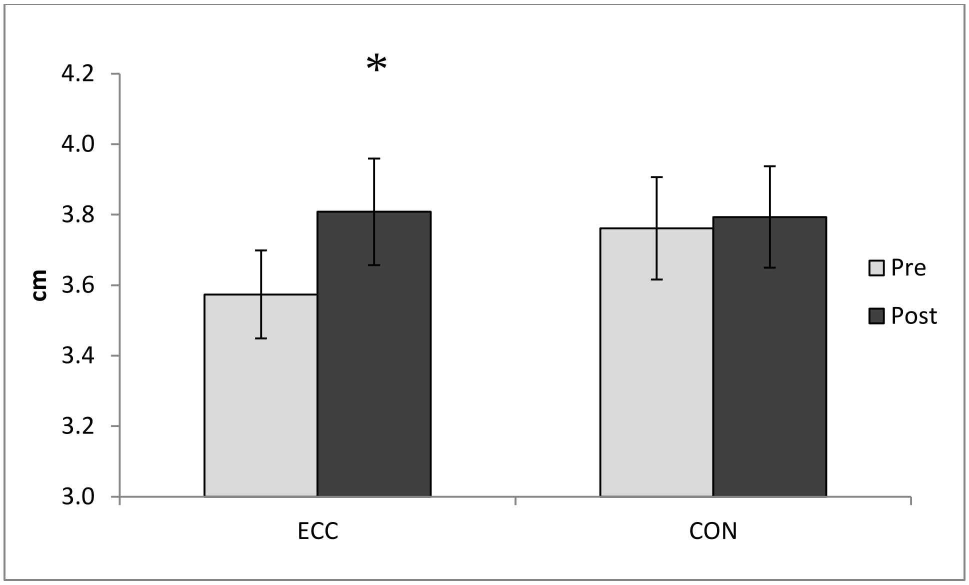


Figure 5.2 Muscle thickness values. * Indicates contraction type × time interaction where ECC training resulted in significantly greater hypertrophy than CON training when averaged across intensities (p<0.05). Values are means ± SEM

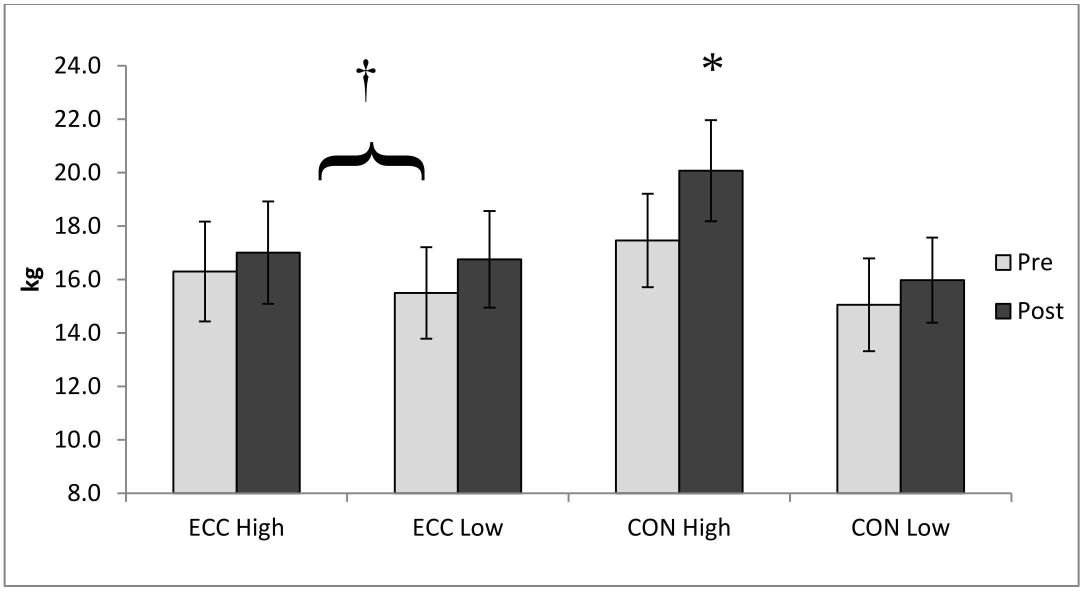
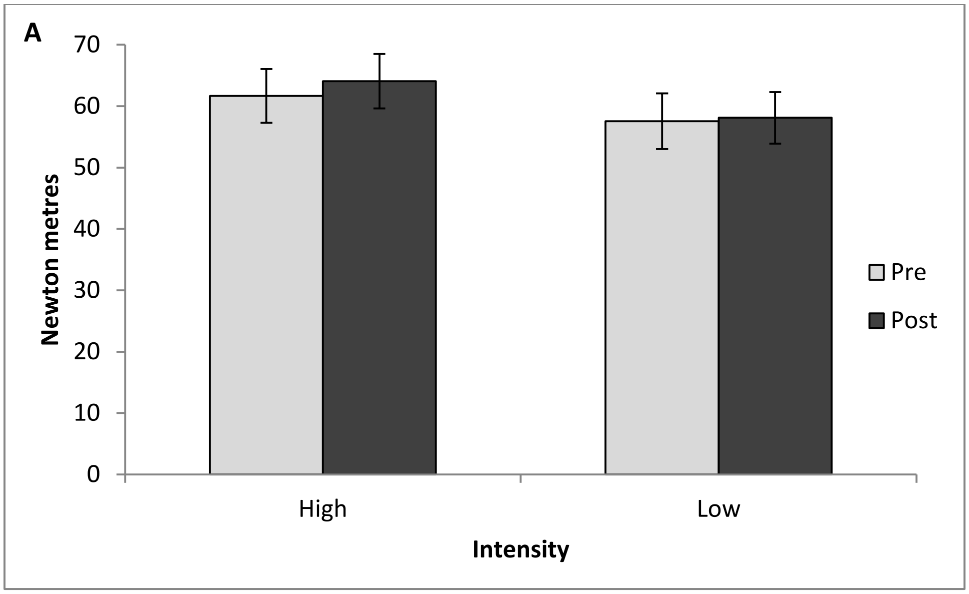


Figure 5.3 Iso-inertial Strength Values. * Indicates Intensity × Contraction Type × Time Interaction where CON HIGH training increased from pre to post (p<0.01). † Indicates a main effect of time for ECC grouped across intensity (p<0.01). Values are means ± SEM

5.4.3 Isokinetic Peak Torque

Repeated measures factorial MANOVA for ECC, CON, and isometric peak torque revealed a significant intensity × time interaction (Pillai's Trace = 0.315, F (3,32) = 4.897, p<0.01 partial η^2 = .315). Univariate factorial ANOVA for ISO indicated no significant main effect of time (GG), [F (1, 34) = 1.707, p=0.200 η^2 = .048], and no significant intensity × time (p=0.383) or contraction type × time (p=0.870) interactions (Figure 5.4A). For CON, univariate factorial ANOVA revealed a significant intensity × time interaction (GG), [F (1, 34) = 5.974, p<0.05 partial η^2 = .149]. Further analysis after splitting the data by intensity revealed a significant effect of time for HIGH (p<0.01) but not LOW (p=0.749) (Figure 5.4B). For ECC, univariate factorial ANOVA revealed a significant intensity × time interaction (GG), [F (1, 34) = 13.583, p<0.01 partial η^2 = .285]. Splitting the data by intensity revealed a significant effect of time for HIGH (p<0.001) but not LOW (p=0.825) (Figure 5.4C). Together these results indicate that HIGH intensity training, when averaged across training contraction type, was effective for increasing both isokinetic ECC and CON but not ISO peak torque. Low intensity training was not effective for increasing any of the isokinetic peak torque tests.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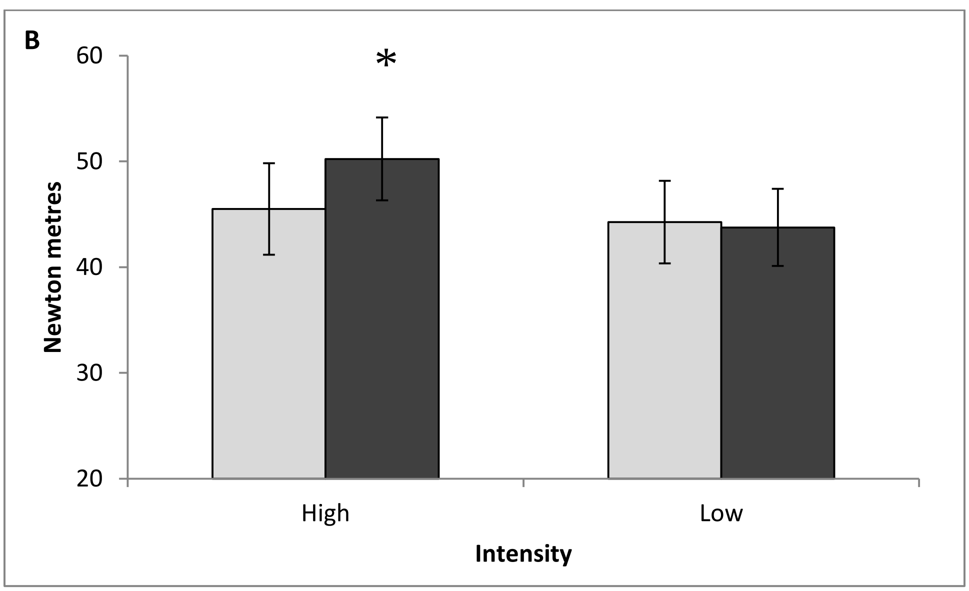
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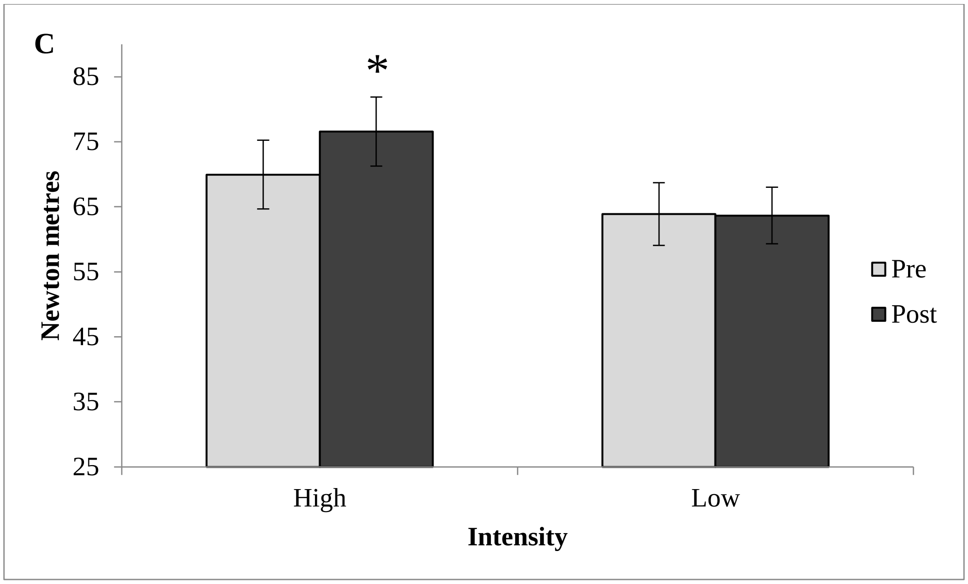

Figure 5.4 Isokinetic peak torque across three contraction types. **A.** Isometric peak torque **B. C**oncentric peak torque. * Indicates intensity × time interaction where change for HIGH is significantly greater than LOW when averaged across contraction types (*p*<0.05). **C.** ECC peak torque. * Indicates intensity × time interaction where change for HIGH is significantly greater than LOW when averaged across contraction types (*p*<0.05). Values are means ± SEM

5.4.4 Ratings of Perceived Exertion

Results of the omnibus ANOVA from RPE revealed a significant main effect of intensity [F (1, 27) = 10.988, p<0.001] indicating that HIGH intensity training resulted in greater RPE when averaged across training contraction types. There was also a significant main effect of training contraction type (p<0.05) indicating ECC training resulted in greater RPE when averaged across training intensities. There were no significant within subjects effects or interactions (Figure 5.5).

5.4.5 Muscle Soreness

Results of the omnibus ANOVA revealed a significant contraction type × time interaction, (GG) [F (1.290, 34.822) = 4.138, p<0.05]. Further analysis revealed that ECC was significantly greater (48.9%) than CON at week 1 when grouped across HIGH and LOW (Figure 5.6).

5.4.6 Muscle Activation (EMG)

Repeated measures factorial MANOVA indicated the effect of time was not significant (Pillai's Trace = 0.015, F (3,32) = 0.246, p=0.784 partial η^2 = .015). There were also no significant intensity × time (p=0.216) or contraction × time (p=0.960) interactions. (Table 5.2)

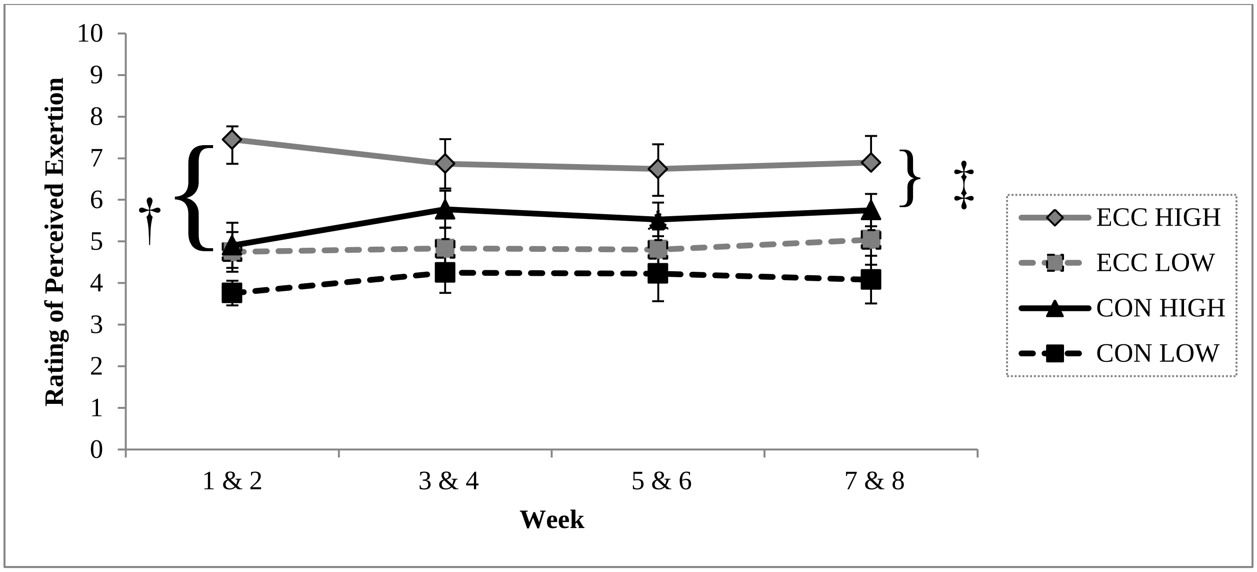

Figure 5.5 Biweekly Ratings of Perceived Exertion. † Indicates a significant main effect of contraction type where ECC training is greater than CON training when averaged across intensities and time ($p<0.05$). ‡ Indicates a main effect of training intensity where HIGH training is significantly greater than low training when averaged across contraction types and time ($p<0.001$). Values are means ± SEM

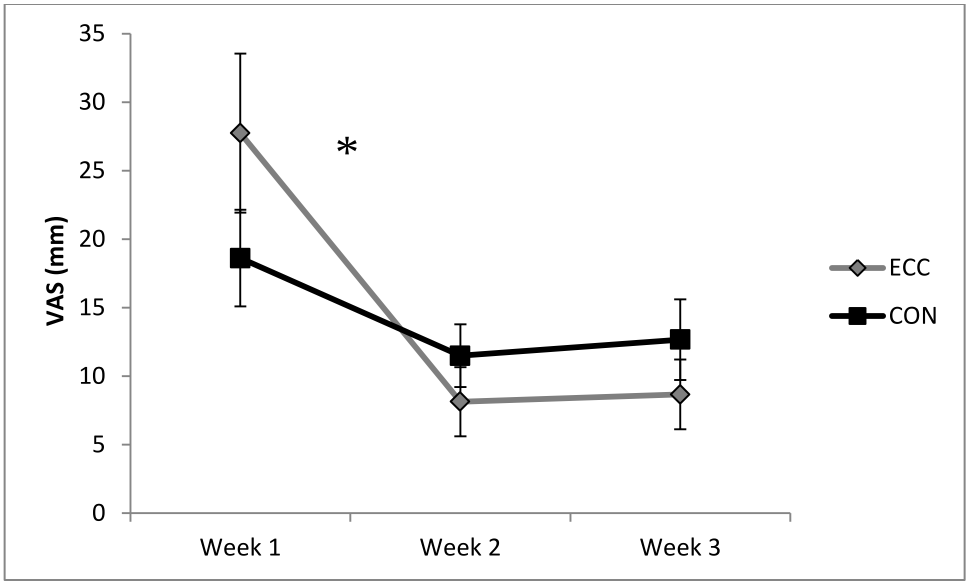

Figure 5.6 Cumulative Weekly Muscle Soreness. * Indicates significant contraction type × time interaction where ECC training is greater than CON training at week 1 (p<0.05) regardless of intensity. Values are means ± SEM

Table 5.2 Muscle Activation and Twitch Torque

GROUP		ECC HIGH	ECC LOW	CON HIGH	CON LOW
Twitch Torque (Nm)	Pre	10.0 ± 2.8	10.2 ± 3.2	9.4 ± 2.2	9.6 ± 3.5
	Post	10.1 ± 2.4	10.3 ± 3.5	9.8 ± 2.2	10.1 ± 3.2
Normalized EMG (arbitrary units)	Pre	0.88 ± 0.13	1.00 ± 0.36	0.70 ± 0.15	0.88 ± 0.27
	Post	0.89 ± 0.22	0.95 ± 0.47	0.79 ± 0.12	0.83 ± 0.25

All data in table is mean ± standard deviation.

5.4.7 Resting Twitch Torque

Results of the omnibus ANOVA indicated the effect of time was not significant (GG), [F (1, 34) = 1.299, p=0.262 η^2 = .037]. There were no significant intensity × time (p=0.966) or contraction type × time (p=0.522) interactions for twitch torque (Table 5.2).

5.5 Discussion

The main finding of the current study was that high intensity iso-inertial training was more effective than low intensity training for increasing strength across both iso-inertial and isokinetic testing modalities (Figures 5.3, 5.4B & 5.4C). Specifically, for iso-inertial 1RM testing, CON HIGH was the most effective for increasing strength pre to post training (Figure 5.3). These results support our primary hypothesis and are not surprising given that the iso-inertial 1RM testing protocol used in this study was performed concentrically and most closely resembled the CON HIGH training group in both contraction type, intensity, and training modality. Additionally, when comparing high versus low intensity training on isokinetic peak torque, only the high intensity training groups increased strength post-training (Figures 5.4B & 5.4C). These findings also support our initial hypotheses and were consistent for CON (Figure 5.4B) and ECC (Figure 5.4C) but not isometric strength (Figure 5.4A). We hypothesized that type of contraction performed in training would display a specificity effect and lead to greater increases in those training specific isokinetic contractions. Surprisingly, this hypothesis was not supported as there were no significant contraction type × time interactions for isokinetic peak torque. The only contraction type specific transfer of strength observed in the study occurred in the CON HIGH group with iso-inertial training, indicating that contraction type specific adaptations occurred only between identical training and testing modalities. This finding is congruent with recent research (Stock et al. 2017) which showed no increase in isokinetic CON strength after iso-inertial CON training but provided evidence of increased iso-inertial CON strength (increased ability to perform repetitions with heavier weight during training).

Our finding of superior iso-inertial strength increase (Figure 5.3) after high intensity CON training is in line with past research suggesting high intensity is superior to low intensity training for increasing strength (Rana et al. 2008; Mitchell et al. 2012; Schoenfeld et al. 2015). Although our findings with iso-inertial strength were expected, our isokinetic strength findings provide new insights into which elements may be most important for transfer of strength between contraction types and across modalities. Our results indicate that high intensity training increased both ECC and CON isokinetic torque but not isometric (Figures5. 4A, 5.4B & 5.4C). This finding supports results from a seminal study by Rutherford and Jones (1986) indicating that training with dynamic contractions leads to much greater strength gains in dynamic, than static (isometric) strength. Our results also indicate that when transferring strength adaptations from iso-inertial training to isokinetic testing, intensity of contraction is more important than contraction type. These finding seem counterintuitive to the principle of specificity for contraction type but are more obvious when interpreted through the lens of intensity specificity, namely the fact that there are important similarities between high intensity iso-inertial training and maximal isokinetic testing. Isokinetic testing requires exertions that are performed at maximal intensities at a fixed velocity. Similarly, both CON HIGH and ECC HIGH training were performed relatively close to maximal intensity (and substantially more close to maximum than either of the LOW intensity groups). For these reasons, both CON HIGH and ECC HIGH were much more specific types of training in comparison to maximal exertion, isokinetic training. Past research has shown that isolated ECC training is inferior in its ability to increase CON strength as comparted to CON training (Higbie et al. 1996; Hortobágyi et al. 1996; Seger et al. 1998; Roig et al. 2009) indicating a contraction type specificity of training does exist. Our data suggests that although contraction type specific adaptations are possible, they are not nearly as robust as intensity specific adaptations when comparing iso-inertial training to isokinetic testing.

A secondary finding of the current investigation was that regardless of intensity, ECC training was more effective for increasing muscle thickness than CON training (Figure 5.2). These results support our initial hypothesis and are in agreement with past research indicating the efficacy of ECC training compared to CON training for muscle hypertrophy (Higbie et al. 1996; Seger et al. 1998; Hortobágyi et al. 1996; Farthing and Chilibeck, 2003b; Roig et al. 2009). Additionally, both high and low intensity ECC training increased muscle thickness, indicating the opposite notion compared to strength, that intensity of contraction was not as important as contraction type for muscle hypertrophy (Figure 5.2). This is in line with past research indicating that similar gains in muscle size are possible with both high and low intensity training (Hisaeda et al. 1996; Chestnut et al. 1999; Tanimoto et al. 2006; Mitchell et al. 2012; Alegre et al. 2015; Krentz et al. 2017). Although we hypothesized that CON training would be inferior to ECC training for muscle hypertrophy, the finding that CON only training did not result in any muscle hypertrophy is both novel and surprising. Numerous past studies using conventional training methods where both the CON and ECC components were included have shown significant muscle hypertrophy with training using varying intensities and nutritional environments (Cureton et al. 1988; Hisaeda et al. 1996; Chestnut et al. 1999; Abe et al. 2000; Burke et al. 2001; Tanimoto et al. 2006; Cornish et al. 2009; Mitchell et al. 2012; Alegre et al. 2015). Based on the current data, which was from CON only training, it may be postulated that the hypertrophy found in many past conventional training studies was due largely in part to the inclusion of the ECC component of contractions. The significance of the ECC component of training is further highlighted when examining studies showing superior hypertrophy when utilizing protocols that have either accentuated (with more weight) (English et al. 2014) or emphasized (with more time) (Krentz et al. 2014) the ECC component during conventional lifts. Conversely, it should be noted that some studies have reported significant muscle hypertrophy after training that included CON only (Housh et al. 1996 ; Stock et al. 2017) or isometric only (Kubo et al. 2001) contractions. Future studies should seek to isolate and better understand the role that the ECC component of conventional training plays in muscle hypertrophy.

It has been previously established that ECC contractions result in lower ratings of perceived exertion (Hollander et al. 2003) than CON contractions and that low intensity ECC training results in lower ratings of perceived exertion than high intensity (Krentz et al. 2017). Less is known about the interplay of RPE when both contraction type and intensity are studied together as in the current study. In agreement with past research (Day et al. 2004), HIGH intensity training resulted in higher RPE scores. A more unexpected finding of the current study was that ECC training resulted in higher RPE values than CON when grouped together over time (Figure 5.5). This result is surprising when compared to past data suggesting lower RPE after ECC compared to CON training (Hollander et al. 2003) although closer examination may explain the inconsistency between past results (Hollander et al. 2003) and the current study. Hollander and colleagues (2003) compared ECC and CON contractions of the same absolute intensity, similar to study number 2 of the current thesis (Figure 4.6) which also showed no difference in RPE between different groups utilizing the same relative load but different levels of ECC emphasis. Conversely, the current study divided ECC and CON training into HIGH and LOW groups relative to strength potential for each contraction type. This resulted in both the HIGH and LOW groups for ECC utilizing a higher relative percentage of 1RM than the CON groups (HIGH 110% vs. 80%, LOW 80% vs. 30%). The fact that the relative load for both ECC groups was higher than the relative loads for CON likely explains the finding of higher RPE in ECC compared to CON training in the current study (Figure 5.5).

Results of our study indicate ECC training results in greater initial (week 1) muscle soreness than CON (Figure 5.6). This finding is not surprising as it is well established that ECC training results in delayed onset muscle soreness (Nosaka and Clarkson, 1996; Tokmakidis et al. 2003; Krentz and Farthing, 2010). There were no effects of intensity of training on muscle soreness, a finding consistent with recent data specific to ECC training (Krentz et al. 2017 – see study 1) which showed similar muscle soreness between supramaximal and submaximal ECC training to failure.

In an attempt to further support the iso-inertial and isokineitc strength findings of the current investigation, measurement of muscle activation (via EMG) was also obtained. Past research suggests that surface EMG is an effective indicator of peripheral neuromuscular changes occurring with training, specifically when used as a simple indicator of changes in site specific activation of target muscles (Häkkinen et al. 2001; Aagaard et al. 2002). Results of the current investigation did not support this idea, as increases in isokinetic peak torque over time and between intensities were not accompanied by observable differences with EMG. In the current study we chose to normalize dynamic EMG values to corresponding peak isometric EMG values to attempt to account for day to day fluctuations in EMG measurement variability (Halaki and Ginn, 2012). Admittedly, though, this process of normalization has the ability to mask real changes in EMG and could potentially result in a Type II error. We felt this was still superior to the option of not normalizing, especially considering our peak isometric torque values did not change pre to post training.

In conclusion, the current study is the first to investigate both high and low intensity training with both iso-inertial ECC and CON contractions. The main finding of optimal increases in strength after HIGH intensity training (CON HIGH for both isokinetic and iso-inertial; ECC HIGH for isokinetic only) provides novel insight into how specificity of training adaptations occur when transferring strength across contraction types and modalities. Our results highlight the importance of high intensity training and its efficacy for increasing strength and support past research in this regard (Rana et al. 2008; Mitchell et al. 2012; Schoenfeld et al. 2015). Of greater novelty regarding our data is the fact that this is especially true when the modality of training is not exactly the same as the modality of testing.

Often training is performed in one setting (field) and then testing is performed differently (laboratory). Practically, this study suggests that it is crucial to ensure intensity is similar between training and testing settings that differ in modality. It should also be noted that isometric strength was not increased after either HIGH or LOW training in the current investigation, indicating that only training with dynamic contractions improved dynamic testing conditions. Although initially reported over 30 years ago (Rutherford and Jones, 1986), there still exists a lack of scientific knowledge regarding training adaptations resulting from isometric based training. This is especially true with regards to iso-inertial isometric training protocols and the relationship between isometric training and dynamic testing results.

Future studies should not overlook isometric training when comparing contraction types. This may be viewed as a limitation of the current study, because we did not include an isometric training condition (only CON and ECC). Additionally, the current study was limited by the fact that only one relatively small muscle group was trained (elbow flexors) and thus extrapolation of these findings to whole body and large more complex movements may be limited. Future studies should seek to investigate this type of training with more complex, functionally relevant movements (i.e. squat or bench press) and across a wider range of testing and training modalities. As well, the current study highlighted the interplay of contraction type and intensity for untrained young adults. Future studies should seek to advance the current results to more specific and diverse populations that could benefit from the refinement of intensity or contraction type specific adaptations. These may include but are not limited to elite athletes (i.e. ECC programs to optimize hypertrophy) or clinical populations (more accessible lower intensity protocols).

Conflicts of Interest: The authors declare that they have no conflict of interest

Chapter 6 – Summary, Implications and Future Research

6.1 Summary of Findings

The goal of this thesis was to extend the accessibility and applicability of ECC focused training by furthering the understanding regarding ECC training performed with common equipment and in practical, easier to perform training protocols. Below you will find brief summaries of the main findings from each of the three studies in this thesis.

6.1.1 Chapter Three, Study One – *The effects of supramaximal versus submaximal eccentric training until volitional fatigue*

An often cited mechanism for the efficacy of eccentric (ECC) training compared to CON (CON) is the ability to produce greater forces during ECC, allowing for training at intensities which are supramaximal to CON 1RM. This type of training may not be practical for everyone as using supramaximal loads may: be intimidating, require greater safety precautions, and lead to greater deleterious effects in the days immediately after training. For this reason, study one of this thesis looked to compare supramaximal to submaximal ECC training. Our results indicated that when training to volitional fatigue, there was no difference in muscle hypertrophy between submaximal and supramaximal ECC training. This finding is in agreement with a growing body of research showing similar hypertrophy after high versus low intensity conventional, concentrically focused training (Hisaeda et al. 1996; Chestnut and Docherty 1999; Tanimoto and Ishii 2006; Mitchell et al. 2012; Alegre et al. 2015). Additionally, our data indicated that submaximal ECC training sessions were perceived to be easier, supporting our idea that this form of training may be efficacious for those who cannot or do not wish to engage in ECC training with loads greater than their CON 1RM.

6.1.2 Chapter Four, Study Two - *Muscle hypertrophy and strength responses to iso-inertial training with eccentric emphasis*

Study number one's finding of similar gains in muscle hypertrophy with submaximal training sheds new light on the effectiveness of ECC training without supramaximal loading. One weakness of study one was that it employed a protocol consisting of isolated ECC training which is less practical and often very difficult to perform in everyday strength training settings. Along with increasing muscle size, lifters seek to increase CON strength due to its importance in everyday activities as well as sport and occupational requirements. For these reasons study two was designed to investigate approaches to manipulate the level of involvement of the ECC phase of training in conventional, dual contraction lifts (CON coupled with ECC). Specifically, the goal was to compare conventional training to altered conventional lifting protocols of equal intensity, which either removed or emphasized the ECC portion of each lift. Study two's findings indicated that conventional training (19.3%, $p<0.001$), CON only (16.0%, $p<0.001$) and CON with an emphasized (longer) ECC phase (14.3%, $p<0.001$) all resulted in increased CON strength compared to control, but that only the ECC emphasized group demonstrated increased muscle hypertrophy (4.4%, $p<0.05$) when compared to the control group. Additionally, eliminating the ECC component (performing CON only) resulted in no muscle growth (-0.3%), similar to that of the control group (-0.7%). Taken together this study highlighted the importance of the ECC phase in conventional training and provided evidence that emphasizing the ECC phase of a lift is an effective way to enhance muscle hypertrophy without significantly affecting CON strength increases.

6.1.3 Chapter Five, Study Three – *The effects of high and low intensity eccentric and concentric iso-inertial training on strength, isokinetic peak torque and muscle hypertrophy*

A majority of the research providing the theoretical evidence regarding what is known about ECC vs. CON training has been performed using isokinetic dynamometry (Higbie et al. 1996; Hortobágyi et al. 1996; Farthing and Chilibeck, 2003; Shepstone et al. 2005; Krentz and Farthing 2010) and rarely have varying intensities of ECC and CON been studied together. Thus, the purpose of study number three was to explore the interplay between high and low intensity ECC and CON training and to assess both iso-inertial and isokinetic strength gains after iso-inertial only training. The main finding of this study was that across both training contraction types, high intensity training was superior to low intensity for increasing both iso-inertial and isokinetic strength. This finding is in line with past research suggesting the superiority of high compared to low intensity training (Rana et al. 2008; Mitchell et al. 2012; Schoenfeld et al. 2015) while further suggesting that this holds true even when testing is done on a different modality than training. Resting twitch torque and muscle activation values were also measured but did not change across time, training intensity, or contractions type.

While intensity was more important than contraction type for strength increase, the exact opposite was true for increasing muscle hypertrophy. Study three data suggested that ECC was more effective for inducing muscle hypertrophy than CON, regardless of training intensity. This finding is in agreement with past ECC vs. CON research highlighting the superior potential for muscle hypertrophy after ECC (Higbie et al. 1996; Seger et al. 1998; Hortobágyi et al. 1996; Farthing and Chilibeck, 2003b; Roig et al. 2009) and with recent research suggesting similar muscle hypertrophy is possible between high and low intensity conventional CON (Hisaeda et al. 1996; Chestnut et al. 1999; Tanimoto et al. 2006; Mitchell et al. 2012; Alegre et al. 2015) or

ECC training (Krentz et al. 2017; Study 1). Together, the findings highlight the specific response of training intensity and contraction type for strength and hypertrophic adaptations while adding important information to the current literature regarding the transferability of strength between iso-inertial and isokinetic modalities.

6.2 Theoretical Knowledge Advancements of Thesis

The hypertrophy and strength outcomes comparing ECC and CON training have been well documented over the last 20+ years (Higbie et al. 1996; Seger et al. 1998; Hortobágyi et al. 1996; Farthing and Chilibeck, 2003b; Roig et al. 2009; Franchi et al., 2014, 2015). Another area of interest has been the role of high versus low intensity training on muscle hypertrophy (see reviews by: Fisher et al. 2013; Schoenfeld et al. 2016; Fisher et al. 2017). The current thesis addressed knowledge gaps related to each of these respective research areas. Specifically, before the completion of study number one, no study had investigated the effects of supramaximal vs. submaximal ECC training performed until volitional fatigue and limited research was available on the effects of high versus low intensity ECC training (Schroeder et al. 2004). Similarly, prior to study number three of the current thesis, very little was known regarding the interplay of intensity of contraction and contraction type on iso-inertial and isokinetic strength increases. Results of the current thesis provide valuable scientific advances on both of these topics.

Although several studies have investigated the muscle hypertrophy responses to high versus low intensity conventional (CON focused) training, very limited research was available regarding the investigated adaptions to high and low intensities of ECC training. Results of the current thesis indicate there is no difference in muscle hypertrophy after supramaximal versus submaximal

ECC training of the elbow flexors. This supports a growing body of literature suggesting that both high and low intensity training have potential to similarly induce muscle hypertrophy (Hisaeda et al. 1996; Chestnut et al. 1999; Tanimoto et al. 2006; Mitchell et al. 2012; Alegre et al. 2015), especially when training is performed until volitional fatigue (Burd et al. 2010; Mitchell et al. 2012). The findings of the current thesis are noteworthy, providing evidence that intensity is of less importance for determining training potential for hypertrophic adaptations. In addition, these findings are important in the ECC training literature as they provide new insights into the potential of submaximal ECC training as a modality that can elicit a lower RPE, and is an accessible, yet highly effective form of ECC training.

The training principle of specificity entails that training responses will be greatest for outcomes most similar to the training performed. Study number three of the current thesis provided new information on how the specificity of strength transfer occurs both between training modalities and across contraction types. Grouped across both ECC and CON training, high intensity training resulted in the greatest increase in strength across both iso-inertial and isokinetic testing. This suggests that even more than specificity of contraction type, intensity of training is the driving force for increasing muscular strength. This result supports past research which also suggests high intensity training is best for increasing strength (Rana et al. 2008; Mitchell et al. 2012; Schoenfeld et al. 2015) further extending this notion in demonstrating a transferability of strength across modalities and contraction types.

6.3 Practical Applications of Thesis

The overarching goal of the entire thesis was to advance the accessibility and applicability of ECC training. The composition of studies making up this thesis provided valuable information on ECC training protocols that are more readily available for a wide variety of people. Knowledge gained from this work allows future research to continue to expand on these findings, extending the data across different populations. Along with valuable proof of principle advancements made in this thesis through exploration of iso-inertial based ECC training, some practical applications warrant discussion. A list and brief explanation of the practical knowledge gained in this thesis are outlined below.

6.3.1 Importance of the Eccentric Component during Conventional Iso-Inertial Lifting

Study number one of this thesis explored isolated ECC training of varying intensities and found no differences in muscle hypertrophy between supramaximal and submaximal training. Theoretically this is a significant advancement in the area of both ECC training and in the area of training intensity for muscle hypertrophy; showing for the first time that both high and low intensity ECC training effectively increase muscle hypertrophy. Practically though, this result was still lacking. Isolated single contraction type training is not only difficult to perform but is less practical and time efficient than training utilizing both a coupled CON and ECC phase. For this reason, the answers revealed in study two may have the most practical relevance of the entire thesis and have led to important practical recommendations. Results of this study revealed that taking extra time during the ECC phase of a conventional lift (referred to as “emphasized” ECC training in this thesis) leads to the greatest adaptations in muscle hypertrophy while not compromising CON strength increase. In addition, the group that performed CON only contractions and eliminated the ECC phase of conventional lifting experienced no muscle hypertrophy and no additional enhancement in CON strength over and above the other training groups. Together these findings highlight the significant role that the ECC phase of lifting plays in all conventional iso-inertial training, even for those that have no need or desire to perform isolated ECC training.

Recommendations:

• When performing conventional CON/ECC coupled iso-inertial training, exercisers are advised to give credence to both the CON and ECC phase of the lift.

• Specifically, taking three seconds to control the ECC phase of the lift will allow exercisers to make the most of potential gains in both strength and muscle hypertrophy.

• This form of emphasized CON/ECC training is more practical than isolated single contraction ECC training, and in comparison leads to similar muscle hypertrophy with greater increases in CON strength.

6.3.2 Eccentric Training and Session Rating of Perceived Exertion

It is traditionally reported that one of the physiological advantages of ECC training is the fact that for a given force, ECC training requires a lower oxygen cost (LaStayo et al. 1999; Meyer et al. 2003) and results in lower RPE than CON training (Hollander et al. 2003). When considered in this light, ECC training appeals to those populations not able to utilize high levels of exertion in training. The current thesis extends the understanding of the relationship between RPE and ECC training. In addition to the finding of comparable muscle hypertrophy reported in study one between supramaximal and submaximal ECC training, there was significantly lower average RPE for the submaximal group. This suggests that submaximal ECC training offers similar benefits in terms of muscle hypertrophy while feeling significantly easier to perform. When comparing ECC versus CON, study number three reported higher RPE after ECC compared to CON averaged across both high and low intensities. This finding is important as it highlights the need to consider relative load (relative to overall 1RM) when prescribing ECC exercise. It is not enough to classify intensity based on the relative intensity for a specific contraction type (i.e. a light ECC contraction versus a heavy ECC contraction). Instead, the actual weight being lifted relative to one's CON maximum must be considered and likely only when absolute loads are equated between ECC and CON can one expect the ECC to exhibit a lower RPE.

Recommendations:

• Submaximal ECC training is more appropriate than supramaximal training when utilizing ECC training in populations which warrant lower a RPE during training.

• ECC training is lower in RPE than CON only when actual absolute loads are equal.

• Lower intensity ECC training as performed in study number one may not necessarily be lower in RPE than other moderate to light load CON training protocols even though it is significantly lower in RPE than higher intensity ECC training.

6.3.3 Eccentric training can be effectively performed safely without expensive equipment or long lasting deleterious effects

Although theoretically beneficial, the practical utilization of many benefits of the ECC phase of lifting are often undervalued, unappreciated, and overlooked by everyday lifters. Two major reasons for this are the apparent need for specialized equipment to perform this type of training and the extensive documentation of the deleterious effects that follow a bout of ECC training. Numerous studies have reported the efficacy of ECC focused training but often involve specialized equipment to isolate high force ECC contractions isokinetically (Higbie et al. 1996; Hortobágyi et al. 1996; Farthing and Chilibeck, 2003; Shepstone et al. 2005; Krentz and Farthing 2010) or accentuate the ECC phase of conventional lifts by adding more weight (English et al. 2014; Walker et al. 2016). All three studies from the current thesis utilized standard dumbbells found in virtually all gyms, employing forms of both isolated and emphasized ECC training.

With regards to observed deleterious effects, as expected, muscle soreness in all three studies was elevated during the first week of training for groups utilizing ECC contractions. But, consistently across both study one and three, muscle soreness significantly declined after week one and remained lowered for the rest of the training. Additionally, there was no difference between ECC and CON contractions after week one in study number three and emphasizing the ECC phase of the lift in study number two did not result in greater muscle soreness compared to other conventional training groups. All in all, the combined results from the current thesis repeatedly demonstrate that iso-inertial loading can be effectively utilized for multiple styles of ECC focused training (isolated or emphasized) and that when programs are appropriately progressed, these forms of training are well tolerated, leading to minimal reported soreness after the first week of training.

Recommendations:

• Progressively designed resistance training programs of both isolated and emphasized ECC training are well tolerated after the initial first week of muscle soreness. Practitioners utilizing ECC emphasized training should be aware of this and appropriately advise those utilizing ECC training of the expected soreness and declines in performance likely experienced in the initial week.

• Both isolated and emphasized iso-inertial ECC training protocols are effective for increasing muscle hypertrophy and strength.

• Emphasized CON/ECC training may be especially relevant as it incorporates the benefits of ECC focused training into everyday conventional training protocols without the need for different equipment and without any additional deleterious effects.

6.4 Limitations & Future Research

With the goal of extending the accessibility and applicability of ECC training, this thesis has advanced the theoretical understanding of iso-inertial ECC training as well as presented some practical information and guidance for those wishing to employ ECC training methods using everyday training modalities. That being said, the current thesis is not without its limitations. Acknowledgement of these limitations is important as their understanding is key for both researchers seeking to advance the current findings as well as practitioners who seek to apply the information gained in this thesis.

6.4.1 Elbow Flexor Training

• All three studies of this thesis focused solely on training the elbow flexor muscles via the concentration curl setup. Elbow flexors were chosen because they are relatively simple to train and measure and have been used to study strength and muscle hypertrophy adaptations many times in our lab (Farthing and Chilibeck, 2003b; Krentz et al. 2008; Krentz and Farthing, 2010). A major disadvantage of using this muscle group for the current thesis is that it does not offer functional specificity for everyday movements.

• Similar to the above point, it must be noted that performance of both isolated and emphasized ECC training utilizing the concentration curl are likely easier to perform that many of the movements that are clinically relevant or that work major muscle groups. Results of the current thesis suggest that iso-inertial training can be performed safely, with regular resistance training equipment (i.e. dumbbells), with little to no complications. Employing such methods in exercises such as the squat or bench press may provide additional, unique challenges (i.e. additional safety considerations or spotting requirements) not witnessed in our single joint elbow flexor training protocol.

• In order to truly continue to extend the applicability and accessibility of ECC training, future research should continue to study muscle groups and incorporate movements that feature larger muscle groups and more clinically relevant movements. The current study provides compelling evidence that iso-inertial ECC training is effective and can enhance conventional resistance training. Future studies should now seek to expand the real life meaningfulness of these results.

6.4.2 Population Studied – College Aged Heterogeneous Sample

• A second limitation of the current thesis is the population which was used in all three studies. Specifically, participants primarily recruited from a university setting were randomly assigned to each group. Although attempts were made to assign equal numbers of males and females to each group, samples were heterogeneous with regards to all other variables including past training experience.

• As a result, findings from the thesis as a whole are broadly generalizable to low to moderately trained college aged males and females but do not provide detailed insight on the effectiveness of iso-inertial based ECC training for specific, more homogenous populations.

• Specifically, it is unknown how highly trained individuals or trained and / or untrained older adults would respond to the various protocols examined in the current thesis.

• Future studies should look to extend the applicability of iso-inertial ECC training by designing and studying more focused and population specific training protocols for more precisely defined populations.

• As noted in study number one, both supramaximal and submaximal isolated ECC training groups experienced a noteworthy number of participant withdrawals during the course of training. Future research should continue to monitor this and seek to better understand if any specific relationship exists between the tolerability and desirability of ECC training in specific populations or with an individual's training backgrounds or experience.

6.4.3 Measurement Limitations

- A final limitation of the current thesis pertains to limitations associated with employed measures as well as limitations regarding the omission of measures or tests. Specifically, the magnitude of improvement in both muscle size and iso-inertial strength must be considered within the context of what is physiologically relevant, as well as the coefficient of variation for each measure. Additionally, although a main focus of the training in all three studies was iso-inertial ECC protocols, no measurement of iso-inertial ECC strength was taken.
- Strength increases across all three studies were consistently in the 1-3kg range. Although significantly different across time for many groups, caution should be taken in interpreting results that are statistically significant but less physiologically relevant in day to day life. Future studies should be cautious of monitoring strength changes that are not only statistically significant but reflect real world physiological implications.
- Coefficients of variation for the current study were not directly tested. Instead, data from prior studies with nearly identical testing protocols were reported. Caution should be taken when interpreting muscle thickness data that was statistically significant but within the range of measurement error for some individuals (base on CV%). Additionally, the CV for iso-inertial strength is reported as less than 1%, but this likely reflects low sensitivity of the measure (only able to test at ~ 1-2kg increments with available dumbbells).
- Iso-inertial ECC strength training was a focus of the thesis. That being said no measurement of iso-inertial ECC strength was taken and ECC strength in general was only monitored via isokinetic peak torque in study three. Future studies should seek to monitor mode specific ECC strength after iso-inertial ECC training. Although, the current thesis generally found ECC

training to be superior for increasing muscle hypertrophy, the importance of improvements in ECC strength for both real life and sport specific movement cannot be overstated.

6.5 CONCLUSION

The current thesis utilized training protocols that were safe and accessible and required equipment found readily available in almost all gyms with the goal of better understanding the potential applications of iso-inertial ECC training. In doing so, findings from this thesis have advanced the theoretical understanding of ECC training for muscle hypertrophy as well as the interplay of intensity of contraction and contraction type for increasing muscular strength. Just as importantly, results of these studies may now be applied not only in the laboratory but in training settings by fitness professionals. Practical findings from the current thesis highlight the unique and important role that the ECC phase of lifting plays in conventional resistance training. Additionally, results from this thesis open the door for future studies to investigate iso-inertial isolated or emphasized ECC training utilizing protocols that may be more affordable, accessible and applicable compared to most ECC training studies previously performed.

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Appendix A

Participant ID Code______

Resistance Exercise, Supplement and Injury Questionnaire

Pre-Screening Questions

1. How many months in your lifetime have you performed resistance training

   (1 month = 3 x per week for the whole month) ____________

2. How many months in the last year have you performed resistance training

   (1 month = 3 x per week for the whole month) ____________

3. How many months have you regularly trained your biceps in your lifetime

   (1 month = 3 x per week for the whole month) ____________

4. How many days have you regularly trained your biceps in the last 2 months

   (1 day = minimum 3 sets of bicep training) ____________

5. Eccentric Exercise training is training when the muscle if lengthened during contraction (ex: lowering phase of a bicep curl).

Have you ever performed pure eccentric training?   Yes   No

6. Are you currently taking any medications or pills that to your knowledge might impact your normal response to resistance training? (i.e. hormone replacement, antibiotics, contraceptive pills, etc.)

Yes or No

7. Are you currently taking any dietary supplements that to your knowledge might impact your normal response to resistance training? (i.e. creatine, protein, vitamins, etc.) Yes or No

9. Have you ever experienced an injury to the bicep, shoulder or any part of the upper body?__________

If yes, what was the injury, when did it occur, what was the duration of this condition?

____

____

10. Is there any reason that you should not participate in maximal strength testing or exercise?

Yes No

If yes, explain ____

Appendix B

Training, RPE, and Soreness Log Participant Details

Training

- All training will be performed until volitional fatigue
    - This is defined as the point where a successful contraction can no longer be completed
        - For groups with concentric contractions this will occur when the complete rep cannot be completed
        - For eccentric only groups this will occur when the dumbbell can no longer be controlled down in the assigned 3 seconds
    - All participants will complete their training at their assigned training percentage
        - Modification of weight will be allowed but must always fall within + / - 10% of the assigned training %
            - Eg: If you are assigned to train at 50lbs then alteration in weight must fall within 45-55lbs
        - Weight Modifications will be made as follows:
            - IF – Participants are not able to perform at least 4 repetitions for all assigned training sets then the dumbbell weight will be lowered for the next training session (as long as the lowered weight falls within 10% of assigned training weight)
            - IF – Participants are able to perform greater than 20 reps for all assigned training sets then the dumbbell weight will be increased for the next training session (again, as long as the weight increase falls within 10% of the assigned training weight)
    - Training should be completed on non-consecutive days and preferably at the beginning of a training session if you are going to be performing strength or aerobic training outside of the study
    - Rest between sets will be 2 minutes
    - All training sessions will be recorded in your training log with weight and reps completed for each assigned set

RPE

- A session RPE will be completed 30 minutes after the completion of that days workout
- RPE will be reported on a scale of 1-10 in accordance with the accompanying verbal descriptions based on the question "How was your workout?"
- This description should be based on your dominant arm training only

Muscle Soreness

- Muscle soreness will be monitored daily for the first 3 weeks of the study and then weekly for the rest of the study
- A single soreness score will be indicated by a mark on a 100mm line
- A standardized movement of lengthening and then contracting the elbow flexors in a slow controlled manor will be performed and then soreness will be reported based on the feeling after completing this movement
- Soreness should always be reported before the start of a new training session on training days
- For weekly soreness reporting (after the 1st 3 weeks) soreness will be reported 24 hours after the final training session of that week

Appendix C

Sample Training Log

Week 1					Week 2			
Date:								
Set	**Weight**	**Reps**	**Weight**	**Reps**	**Weight**	**Reps**	**Weight**	**Reps**
1								
2								
3								
4	xxxxxxxx	xxxxx						
5	xxxxxxxx	xxxxx	xxxxxxxx	xxxxx				
6	xxxxxxxx	xxxxx	xxxxxxxx	xxxxx	xxxxxxx	xxxxx		
Session RPE								

3 week 1RM___________________________ **Prescribed Training Intensity ___________________**

Week 3						
Date:						
Set	**Weight**	**Reps**	**Weight**	**Reps**	**Weight**	**Reps**
1						
2						
3						
4						
5						
6						
Session RPE						

Week 4						
Date:						
Set	**Weight**	**Reps**	**Weight**	**Reps**	**Weight**	**Reps**
1						
2						
3						
4						
5						
6						
Session RPE						

Week 5						
Date:						
Set	**Weight**	**Reps**	**Weight**	**Reps**	**Weight**	**Reps**
1						
2						
3						
4						
5						
6						
Session RPE						

6 week 1RM____________________________ **Prescribed Training Intensity**___________________

Week 6						
Date:						
Set	**Weight**	**Reps**	**Weight**	**Reps**	**Weight**	**Reps**
1						
2						
3						
4						
5						
6						
Session RPE						

Week 7						
Date:						
Set	**Weight**	**Reps**	**Weight**	**Reps**	**Weight**	**Reps**
1						
2						
3						
4						
5						
6						
Session RPE						

Week 8						
Date:						
Set	**Weight**	**Reps**	**Weight**	**Reps**	**Weight**	**Reps**
1						
2						
3						
4						
5						
6						
Session RPE						

Appendix D

Muscle Soreness Log

Only report soreness of your dominant arm

Week 1

Day 1 Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 2 Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 3 Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 4 Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 5 Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 6 Date_______________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 7 Date_______________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Muscle Soreness Log

Only report soreness of your dominant arm

Week 2

Day 8 Date_______________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 9 Date_______________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 10 Date_______________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 11 Date_______________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 12 Date_______________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 13 Date_______________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 14 Date_______________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Muscle Soreness Log

Only report soreness of your dominant arm

Week 3

Day 15 Date_______________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 16 Date_______________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 17 Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 18 Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 19 Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 20 Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Day 21 Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Muscle Soreness Log

Only report soreness of your dominant arm

Week 4-8

24 hour post Week 4   Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

24 hour post Week 5   Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

24 hour post Week 6   Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

24 hour post Week 7   Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

24 hour post Week 8   Date________________
Please rate the pain in your biceps after completing the lengthening and contracting movement of the biceps

no pain I____I extreme pain

Appendix E Modified RPE Sclae

Rating	Descriptor
0	Rest
1	Very, Very Easy
2	Easy
3	Moderate
4	Somewhat Hard
5	Hard
6	–
7	Very Hard
8	–
9	–
10	Maximal